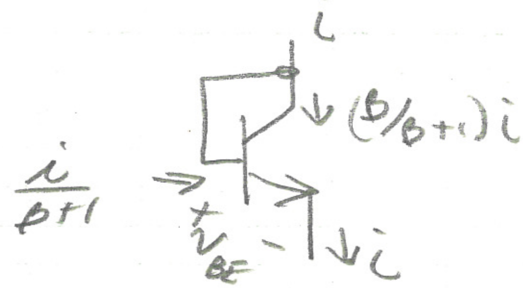
# Chapter 8 Notes ECE 476 Sp16

## Diode-connected BJT




$$\underbrace{\frac{i}{\beta+1}}_{i_B} + \underbrace{\left(\frac{\beta}{\beta+1}\right)i}_{i_C} = \left(\frac{\beta+1}{\beta+1}\right)i = \underbrace{i}_{i_E}$$

F.B = forward bias

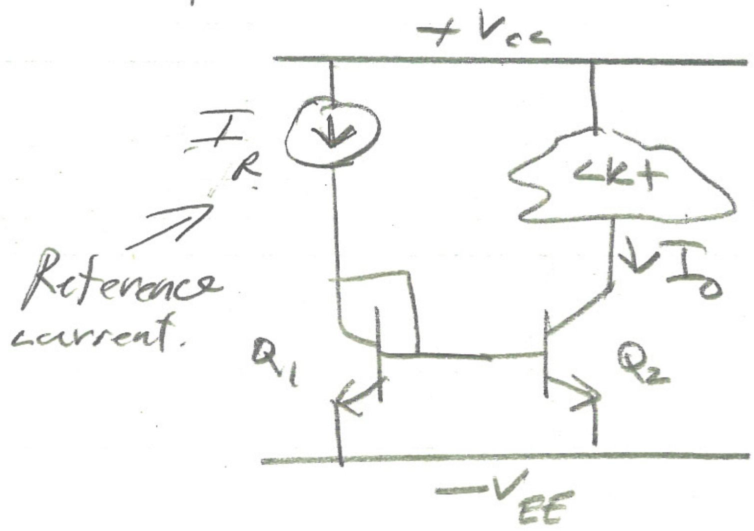
Acts just like normal BJT. It's the way diodes are implemented on a IC

$$i = i_E \doteq I_{ES}\left(e^{v_{BE}/U_T} - 1\right) \simeq I_{ES}e^{\frac{v_{BE}}{U_T}} \text{ if F.B.}$$

$U_T$ = Thermal voltage $= \frac{kT}{q} = 25.9\,mV$ at $T = 300K$

$I_{ES}$ = saturation current

## Simple current mirror



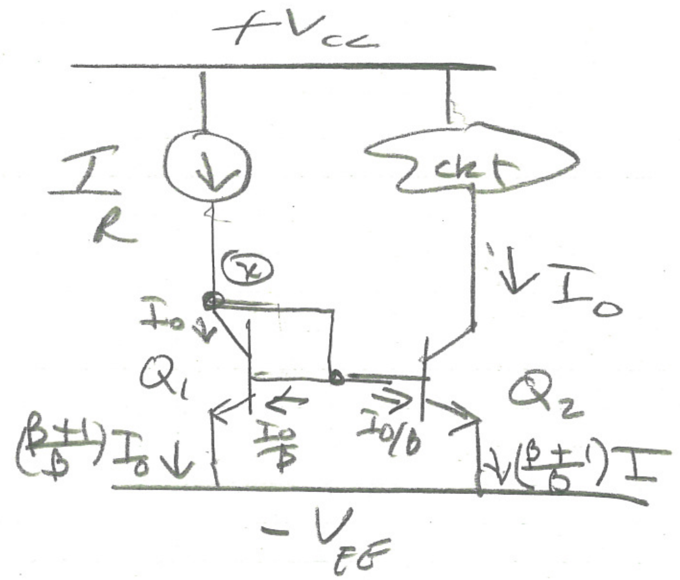

output current

$I_O = I_R$ if

$\beta = \infty$, $V_A = \infty$

and $Q_1, Q_2$ matched!

$I_{ES1} = I_{ES2}$




$\beta$ is finite

$V_A = \infty$

$\leftarrow V_{CE2} > V_{CE,SAT}$

$Q_1, Q_2$ matched

$I_{E1} = I_{E2}$ since $V_{BE1} = V_{BE2}$ and the transistors are matched ($I_{ES1} = I_{ES2}$)!

Write KCL at node $x$

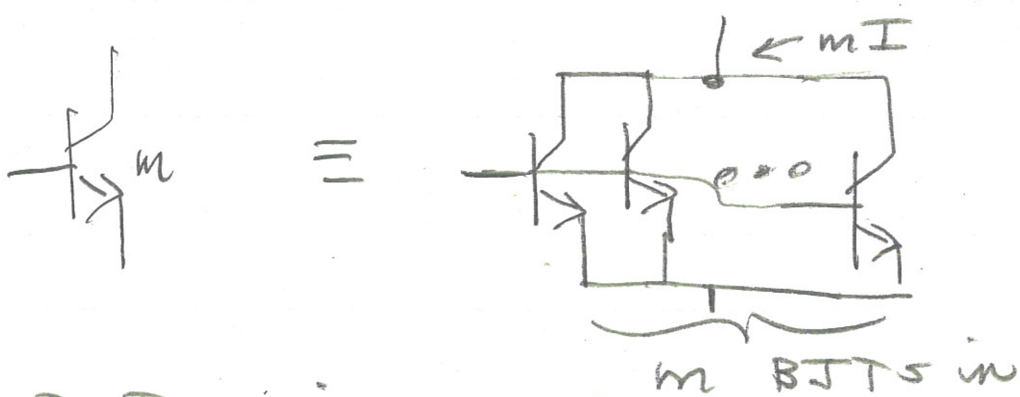
$$I_R = \frac{I_o}{\beta} + \frac{I_o}{\beta} + I_o = I_o\left(1 + \frac{2}{\beta}\right)$$

so * $\boxed{I_o = \dfrac{I_R}{(1 + 2/\beta)}}$

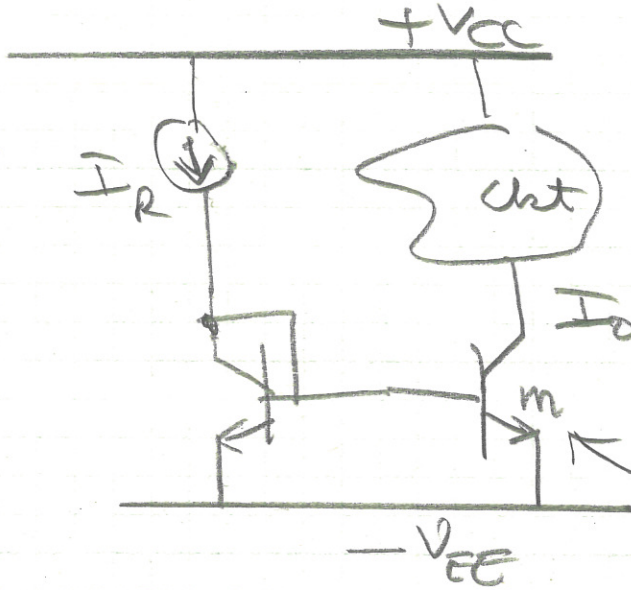
Note as $\beta \to \infty$, $I_o \to I_R$!

$I_o \approx I_R\left(1 - \frac{2}{\beta}\right)$ Taylor Expansion!

If $\beta = 100$ the $I_o$ is ~2% less than $I_R$!




Each BJT carries current $I$ so total current is $mI$ says KCL!




$\beta = \infty$

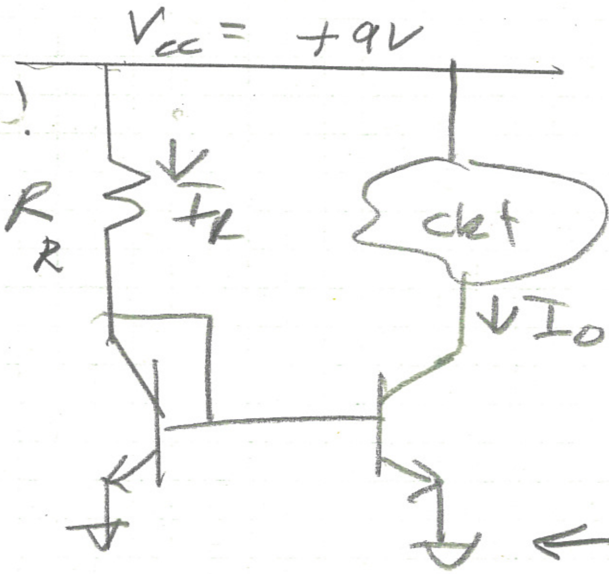
$V_A = \infty$

$I_o = m I_R$ BJTs matched

multiplier, m
m BJTs in parrallel so m times the current.

How do you build, $I_R$?

Use a resistor!
cheap!




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

Here we let $V_{EE} = 0V$ i.e. gnd

$$* \boxed{I_R = \frac{V_{cc} - V_{BE}}{R}} = \frac{9V - 0.7}{R_R}$$

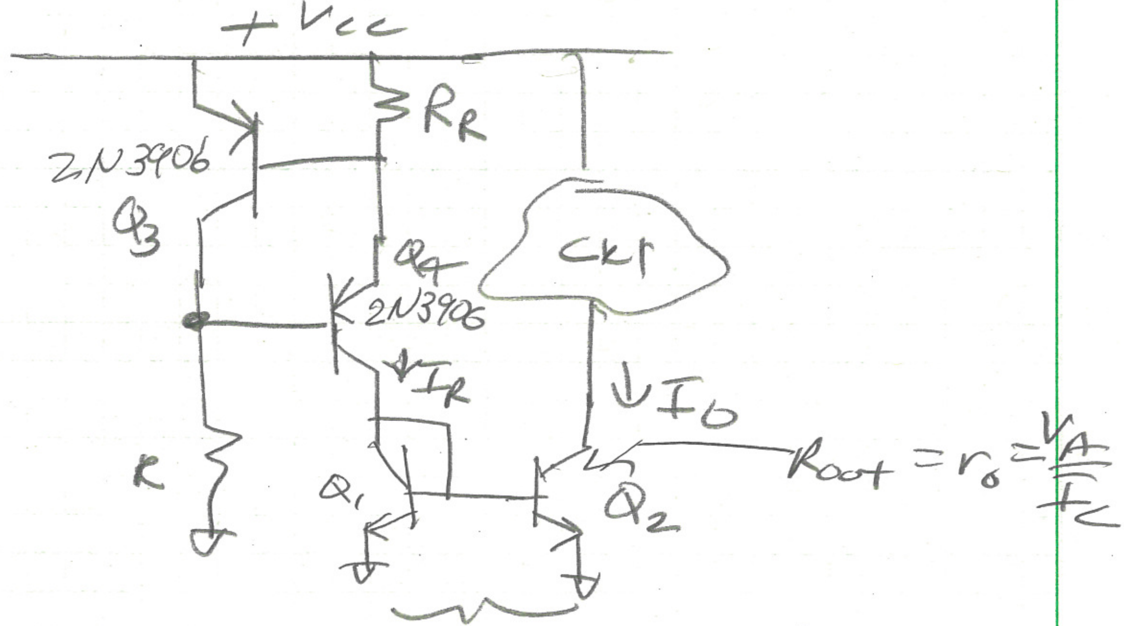
If $R_R = 1k\Omega$, then $I_R = 8.3mA$

$$\boxed{R_R = \frac{V_{cc} - V_{BE(ON)}}{I_R}} *$$

If $V_{cc}$ changes then $I_R$ changes. 4

We have a current source that is sensitive to supply voltage.

Here is how to build a current source less sensitive to supply voltage.




$\beta = \infty$

$V_A = \infty$

simple current mirror

$Q_1$, $Q_2$ perhaps 2N3904 s

R just turns $Q_3$ on so that $V_{EB} \simeq 0.7$

$$* \boxed{I_R = \frac{V_{EB}}{R_R}} \Rightarrow \boxed{R_R = \frac{V_{EB}}{I_R}} *$$

If $R_R = 1K$ then $I_R = \frac{0.7V}{1K} = 700\mu A$.

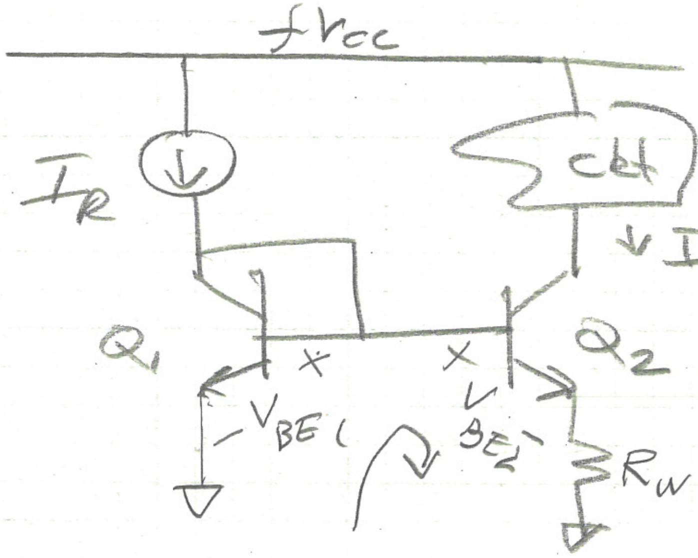
Value of R not critical.

When in doubt use 10K.

So make $R = 10K\Omega$.

Section 8.6.2 (5)

## Widlar Current Mirror




$\beta = \infty$
$V_A = \infty$
Matched BJTs

**KVL**

$$V_{BE1} - V_{BE2} - I_o R_W = 0 \qquad (1)$$

Recall

$$i_E \cong I_{ES} e^{v_{BE}/U_T} \Rightarrow v_{BE} = U_T \ln\left(\frac{i_E}{i_{ES}}\right)$$

So Eqn (1) becomes

$$U_T \ln\left(\frac{I_R}{I_{ES}}\right) - U_T \ln\left(\frac{I_o}{I_{ES}}\right) - I_o R_W = 0$$

Recall $\ln(a/b) = \ln(a) - \ln(b)$

$$U_T \ln\left(\frac{I_R}{I_o}\right) = I_o R_W$$

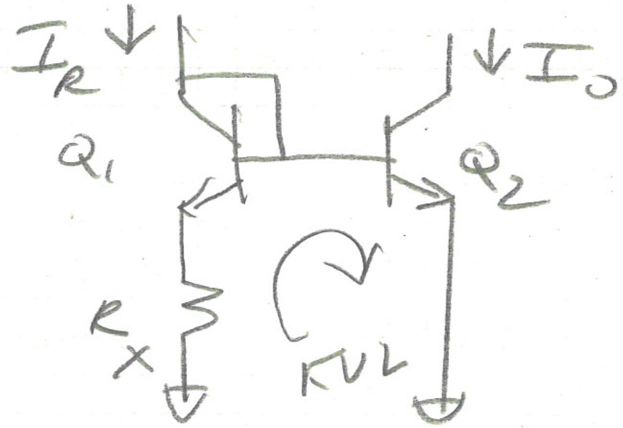
$$\boxed{R_W = \frac{U_T \ln\left(\frac{I_R}{I_o}\right)}{I_o}} \quad *$$

Suppose we have a reference current of 1mA and we want an output current of 100μA, what $R_W$ should we use.

$$R_W = \frac{U_T \ln\left(\frac{1mA}{100\mu A}\right)}{0.1\,mA} \simeq \frac{60mV}{0.1\,mA}$$

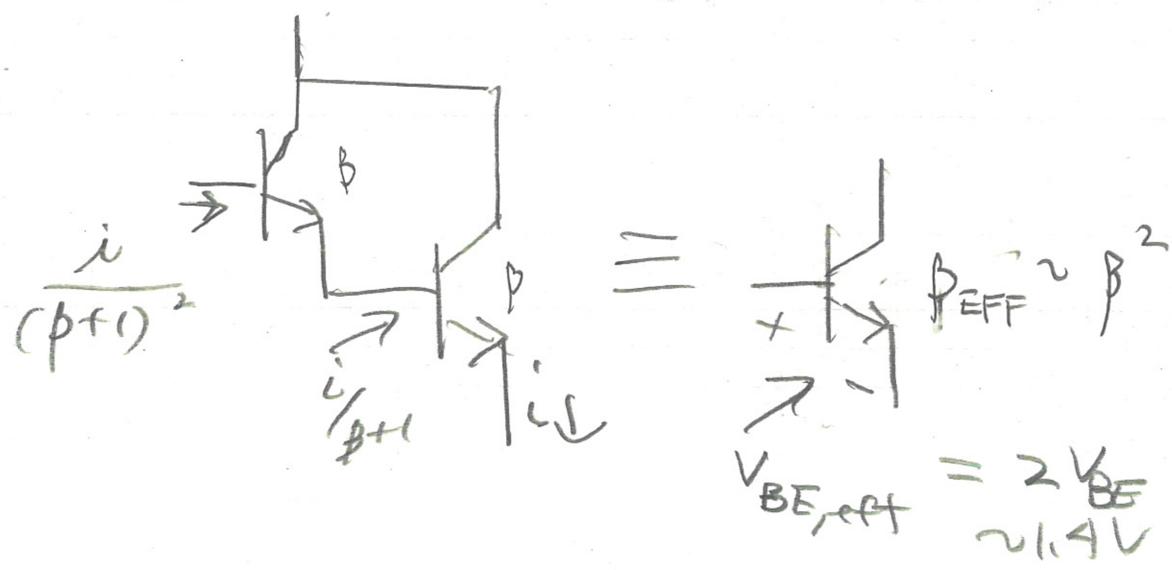
$$R_W = 0.6K\Omega = 600\Omega\,!$$

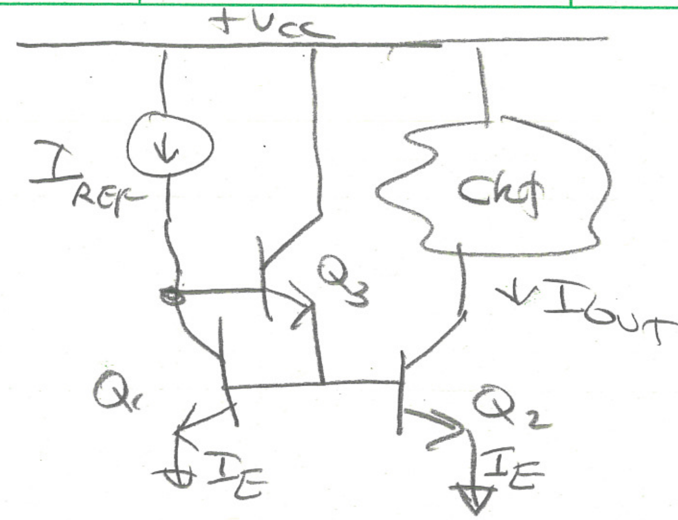
We can also do current multiplicator




Can relate $I_0$ to $I_R$ by writing KVL around the loop!

Darlington pair Section 8.7.2






$$I_{E3} = \frac{2 I_E}{\beta+1} = \frac{2}{\beta}\underbrace{\left[\frac{\beta}{\beta+1} I_E\right]}_{I_{OUT}}$$

$$I_{OUT} = \left(\frac{\beta}{\beta+1}\right) I_E = I_C \Rightarrow I_C = \frac{\beta+1}{\beta} I_{OUT}$$

$$I_{REF} = I_C + \frac{I_{E3}}{\beta+1}$$

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

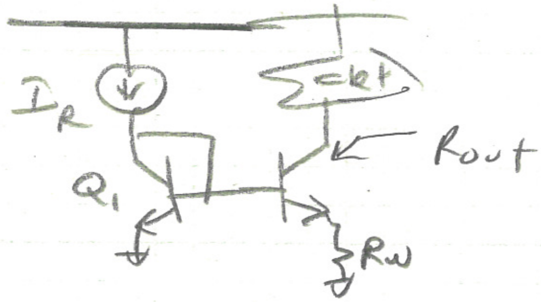
$$I_{REF} = \left[\frac{(\beta+1)^2}{\beta(\beta+1)} + \frac{2}{\beta(\beta+1)}\right] I_{OUT}$$

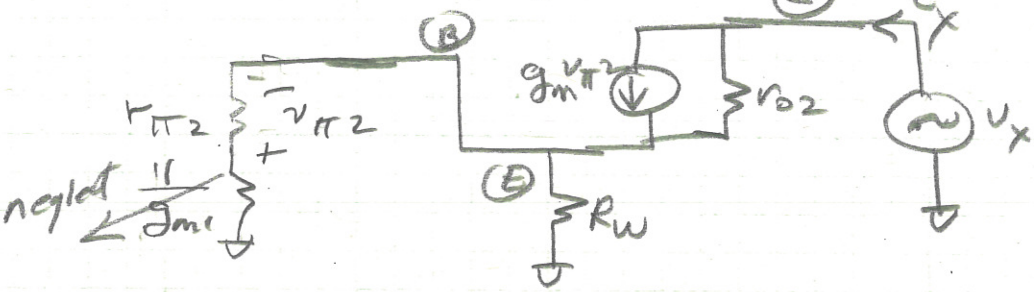
$$I_{OUT} = \left[\frac{\beta(\beta+1)}{(\beta+1)^2+2}\right] I_{REF}$$

$$\simeq \frac{1}{1+\frac{2}{\beta^2}}$$

Base current compensation

Find output resistance of Widlar current mirror




Write KCL at C node

$$i_x = g_{m2} v_{\pi 2} + (v_x - v_e) g_{o2}$$

But $v_{\pi 2} \simeq -v_e$

$$i_x = -g_{m2} v_e - v_e g_{o2} + v_x g_{o2}$$

But $v_e = i_x (R_W \parallel r_{\pi 2}) = i_x \left( \frac{1}{G_W + g_{\pi 2}} \right)$

$$i_x = -(g_{m2} + g_{o2})\, i_x \left( \frac{1}{G_W + g_{\pi 2}} \right) + v_x g_{o2}$$

$$i_x \left[ 1 + \frac{g_{m2} + g_{o2}}{G_W + g_{\pi 2}} \right] = v_x g_{o2}$$

$$R_{out} = \frac{v_x}{i_x} = r_{o2} \left[ 1 + \frac{g_{m2} + g_{o2}}{G_W + g_{\pi 2}} \right]$$

If $g_{\pi 2} \ll G_W$ & $g_{o2} \ll g_{m2}$

$$\boxed{R_{out} \simeq r_{o2} [1 + g_{m2} R_W]}$$