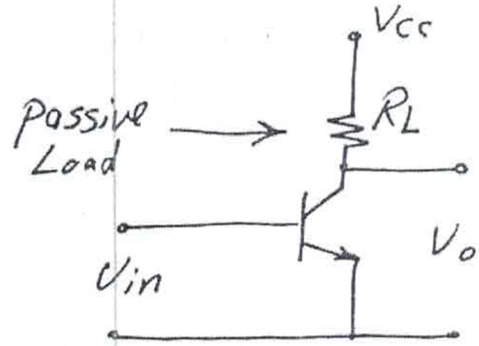
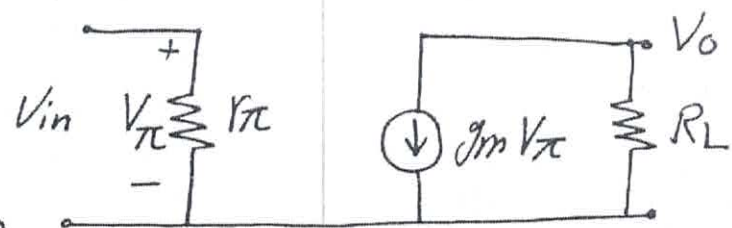
Current sources

Introduction :-

Active Load :-



* $V_o = (-g_m V_\pi) R_L$
* $V_{in} = V_\pi$



∴ Voltage gain is

$$\boxed{A_V = \frac{V_o}{V_{in}} = -g_m R_L}$$

* To increase the voltage gain, we have to increase R_L.

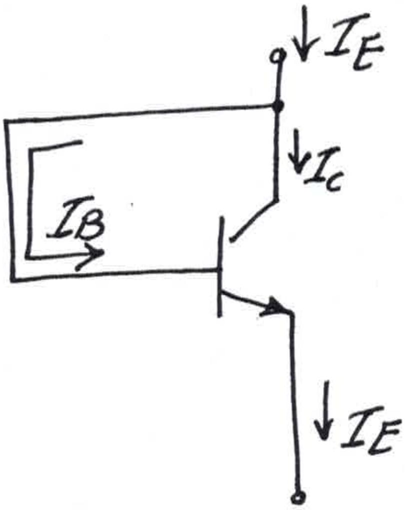
Disadvantages of increasing R_L :-

1. Increase power dissipation
2. Large chip area required for R.
3. Unstable Q-point.

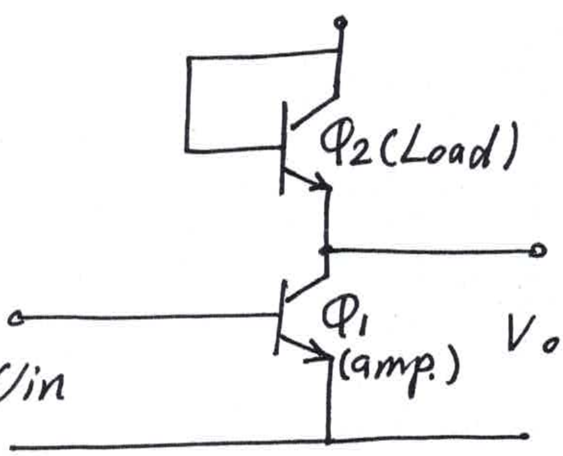
So, R_L is replaced by an Active Load

Diode Connected transistor:-

npn



Active Load (npn):-



$$* \; R_{out}(Q_2) = \frac{r_\pi}{1+\beta} = R_L$$

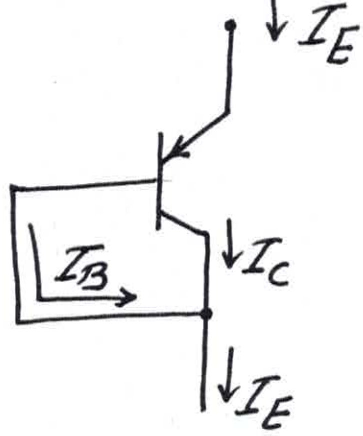
$$* \; A_V = -g_m R_L$$

$$= -g_m r_\pi \frac{1}{1+\beta}$$

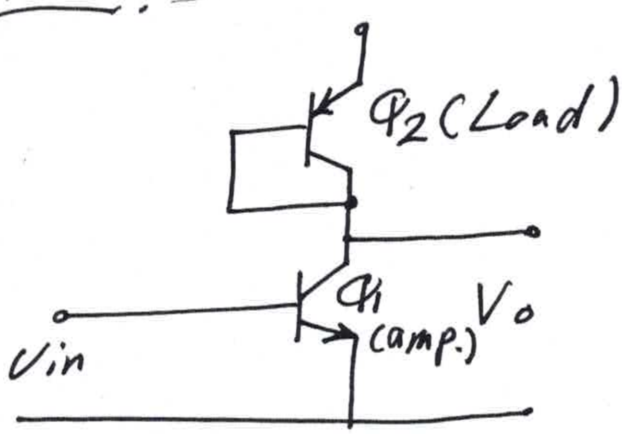
$$= -\frac{\beta}{1+\beta}$$

$$\boxed{A_V \cong -1}$$ Low gain

pnp



Active Load (pnp)



$$* \; R_{out}(Q_2) \cong r_o = \frac{V_A}{I_C} = $$

$$* \; \boxed{A_V = -g_m r_o}$$

$r_o = 40 k\Omega \longrightarrow 100 k\Omega$

$\therefore$ higher gain than npn

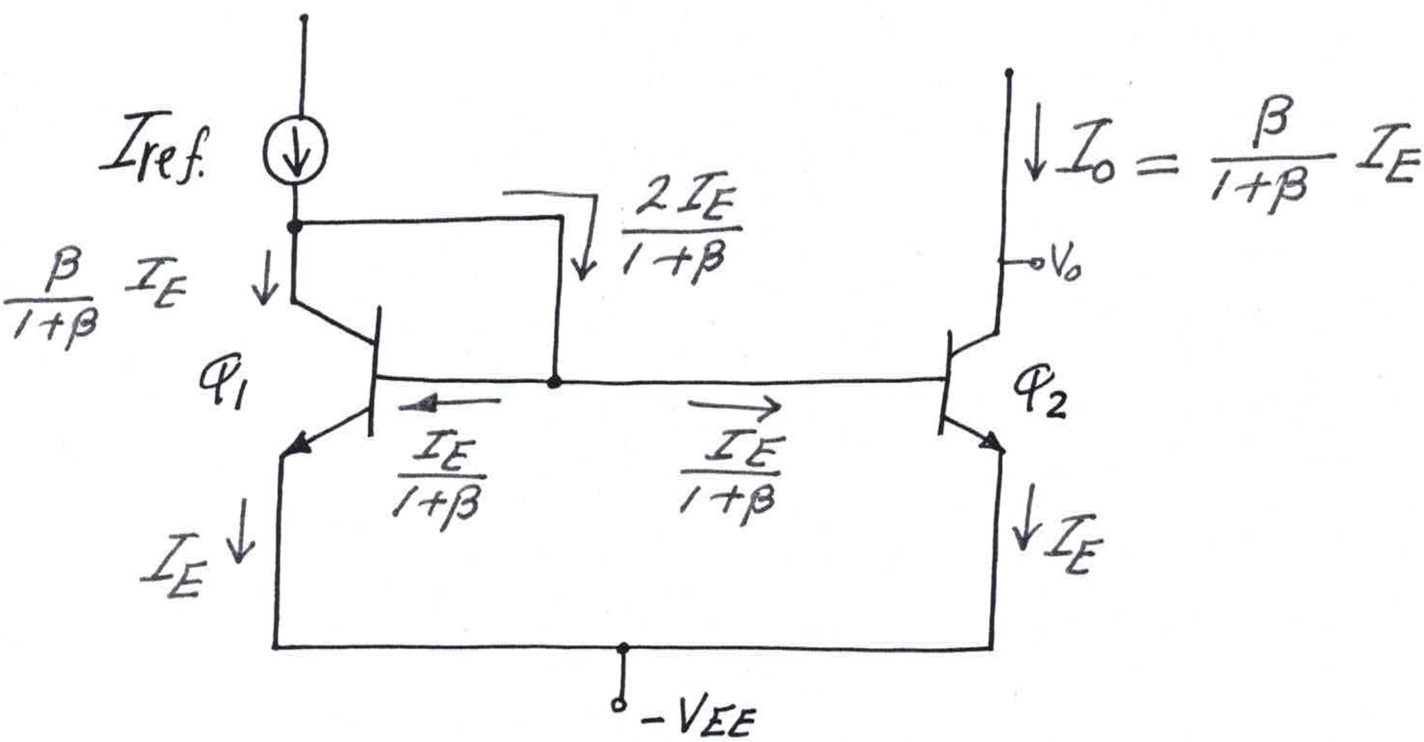
where $r_o = \frac{V_A}{I_C}$

V_A = early Voltage

Current-Sources :-

C.S $\Rightarrow$ Used for biasing amplifiers with active Load with Constant current and High output resistance.

1 Current mirror :-



* Q_1 and Q_2 are matched (identical) and operating in the active mode.

Since $I_C = I_S \, e^{\frac{V_{BE}}{V_T}}$

and $V_{BE1} = V_{BE2}$ $\therefore$ $I_{C1} = I_{C2}$

$\therefore \quad V_{BE1} = V_{BE2}$

* $I_{B1} = I_{B2} = \dfrac{I_E}{1+\beta}$

* $I_{C1} = I_{C2} = \dfrac{\beta}{1+\beta} I_E$

* $\boxed{I_o = \dfrac{\beta}{1+\beta} I_E}$ $\boxed{1}$

but $\quad I_{ref} = \dfrac{\beta}{1+\beta} I_E + \dfrac{2}{1+\beta} I_E$

$$\boxed{I_{ref} = \left(\frac{\beta+2}{1+\beta}\right) I_E} \ \boxed{2}$$

$\boxed{1} \div \boxed{2} \quad \therefore \quad \dfrac{I_o}{I_{ref}} = \dfrac{\beta}{\cancel{1+\beta}} \cdot \dfrac{\cancel{1+\beta}}{\beta+2}$

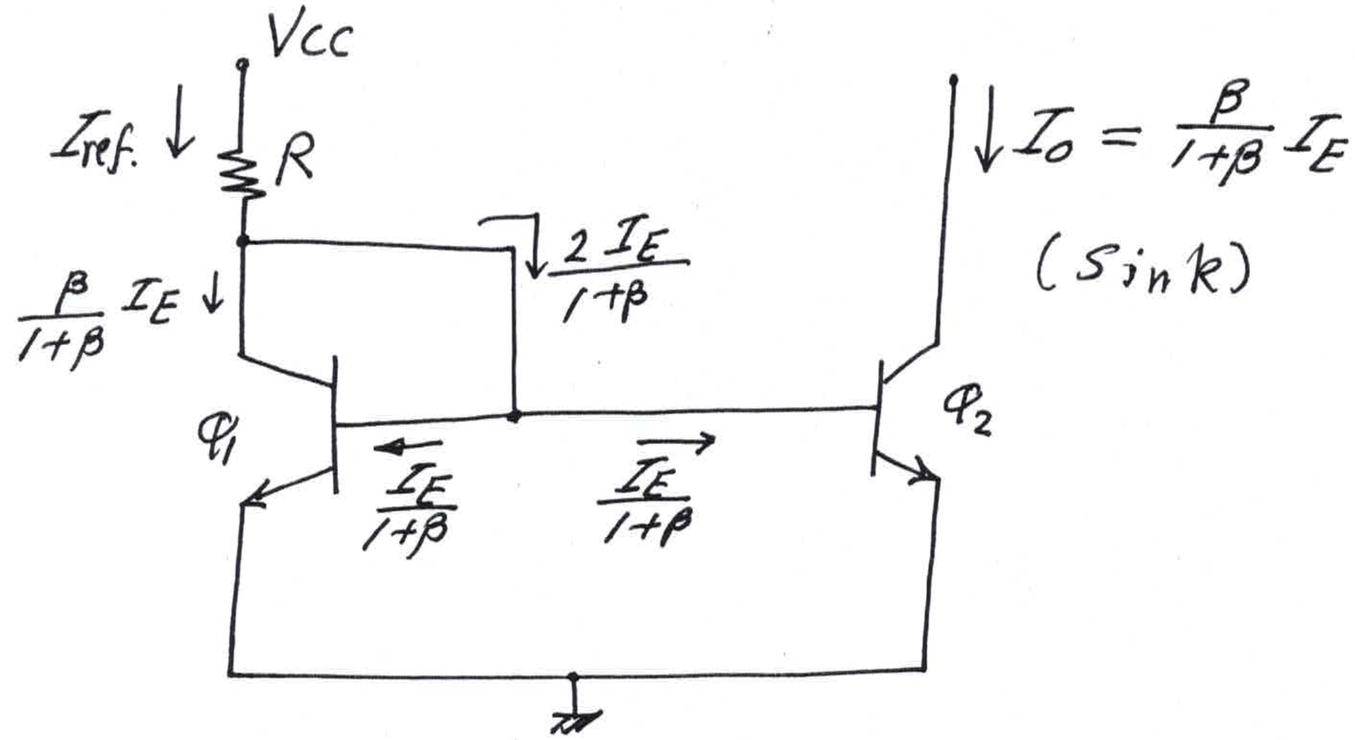
$$\frac{I_o}{I_{ref}} = \frac{\beta}{\beta+2} = \frac{1}{1+\frac{2}{\beta}}$$

$\therefore \quad I_o = \dfrac{I_{ref}}{1+\frac{2}{\beta}}$, if β Large فقط $\boxed{I_o \cong I_{ref}}$

* <u>With Early Effect (VA)</u>

$$I_o = \frac{I_{ref}}{1+\frac{2}{\beta}}\left(1 + \frac{V_o + V_{EE} - V_{BE}}{V_A}\right) \Rightarrow$$

Simple (mirror) Current Source :-

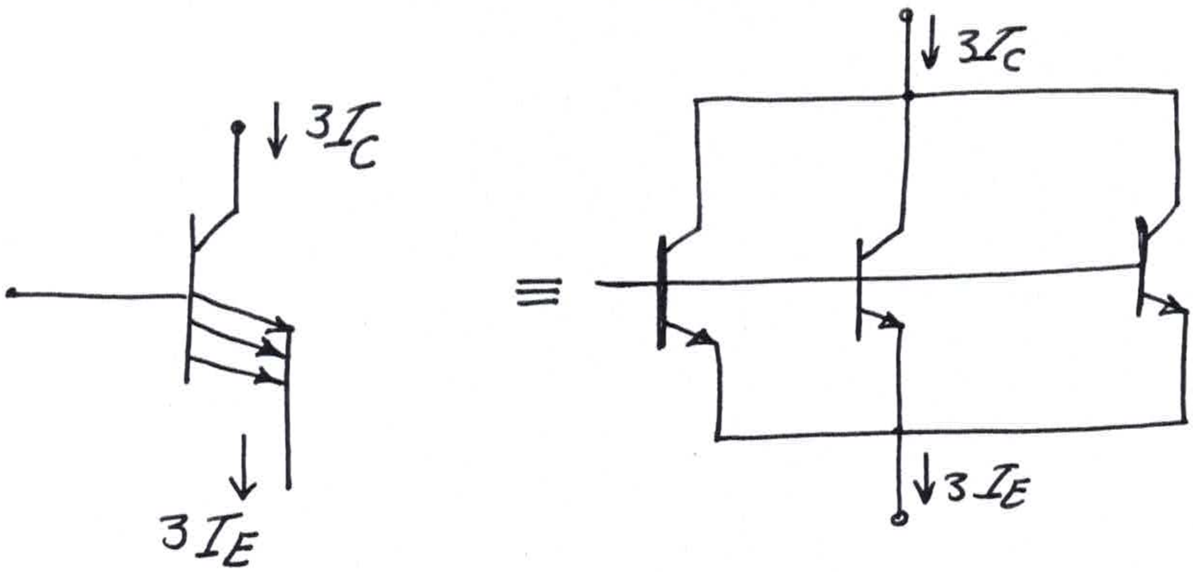


$$* \quad \boxed{I_o = \frac{I_{ref}}{1+\frac{2}{\beta}} = \frac{1}{1+\frac{2}{\beta}} \frac{V_{CC}-V_{BE}}{R}}$$

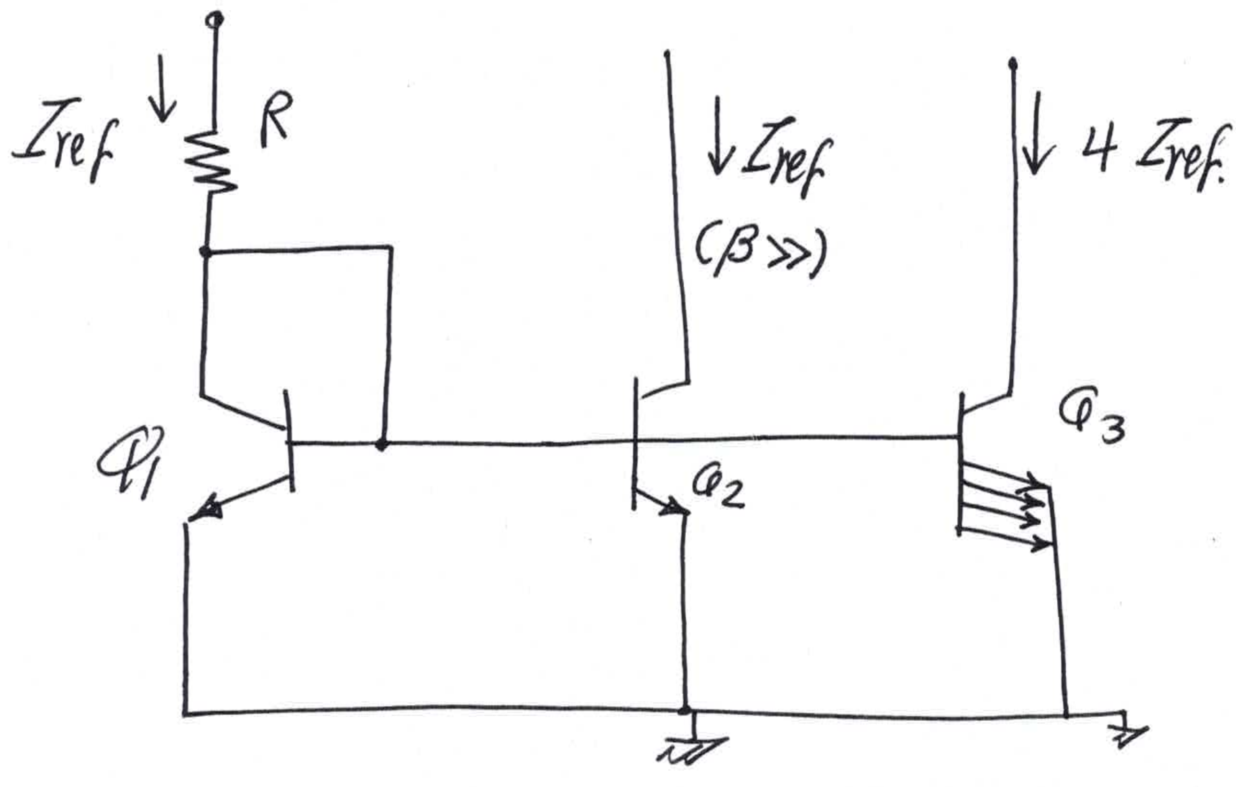
Disadvantages :-

* Large chip area needed for R.
* The dependence of I_o on the finite (β) of BJT.
* The output resistance $r_o = \frac{V_A}{I_o}$ is limited by $40 k\Omega \longrightarrow 100 k\Omega$
* operating in the range of mA only.

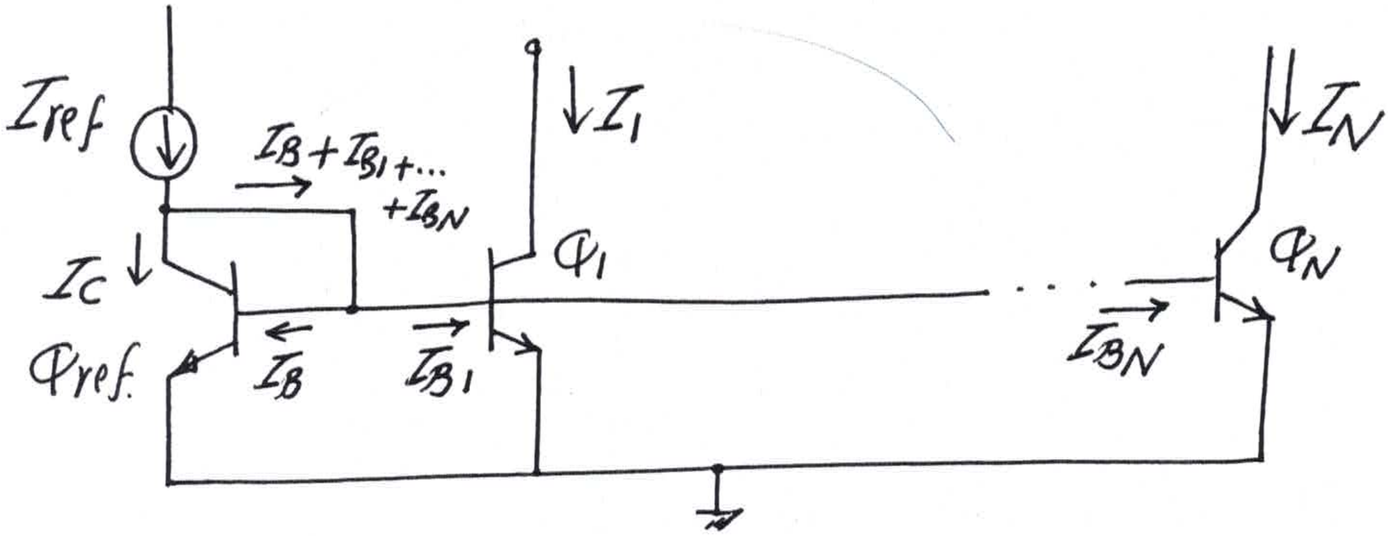
Current Repeater (Multiple Current Source)



EX.



N-output Current Mirror:-



Q_1, Q_2, ..., Q_N are matched (identical)

$\because \quad V_{BE} = V_{BE_1} = V_{BE_2} = \cdots = V_{BEN}$

$\therefore \quad I_C = I_{C1} = I_{C2} = \cdots = I_N$

$I_B = I_{B1} = I_{B2} = \cdots = I_{BN}$

$* \quad I_{ref} = I_C + I_B + I_{B1} + I_{B2} + \cdots + I_{BN}$

$I_{ref.} = I_C + (N+1)\, I_B$

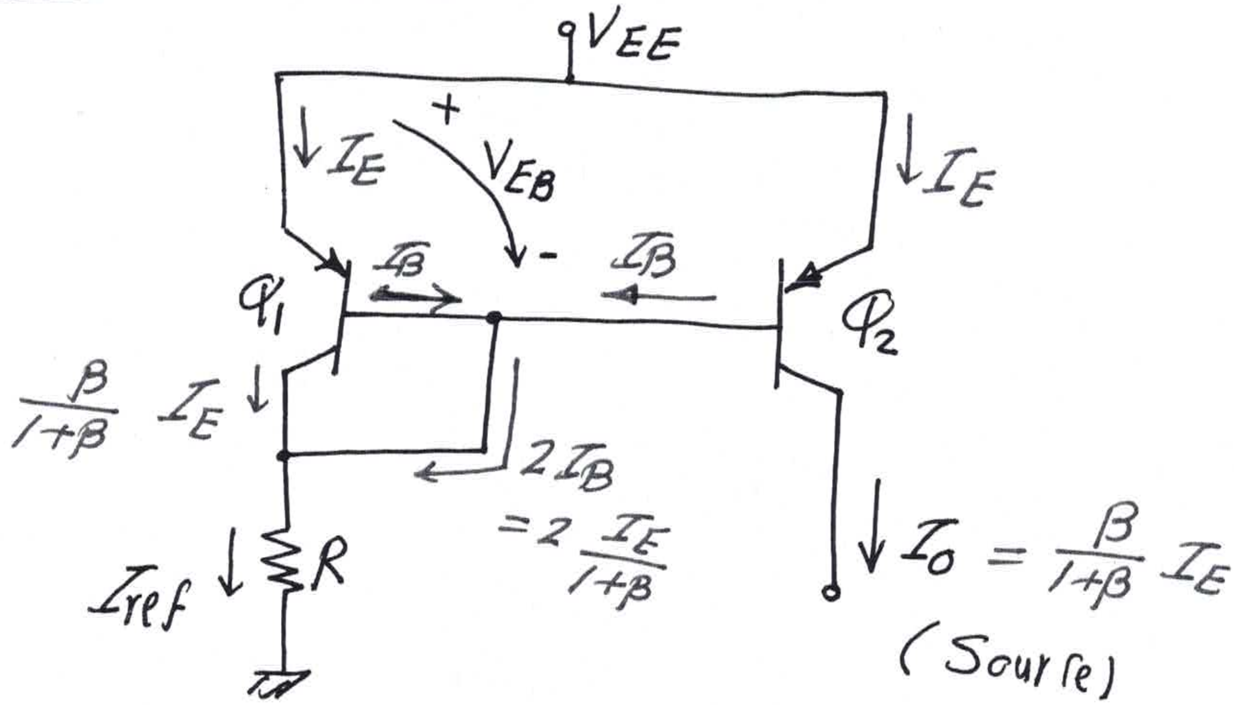
$= I_C + (N+1)\, \frac{I_C}{\beta}$

$\therefore \quad I_{ref} = \left[1 + \frac{N+1}{\beta}\right] I_C \quad , \quad I_C = I_N$

$$\therefore \quad I_{ref} = \left[1 + \frac{N+1}{\beta}\right] I_N$$

$$\therefore \quad \boxed{I_N = \frac{I_{ref}}{1 + \frac{N+1}{\beta}} = I_1 = I_2 = \cdots}$$

Current Source with pnp transistor :-



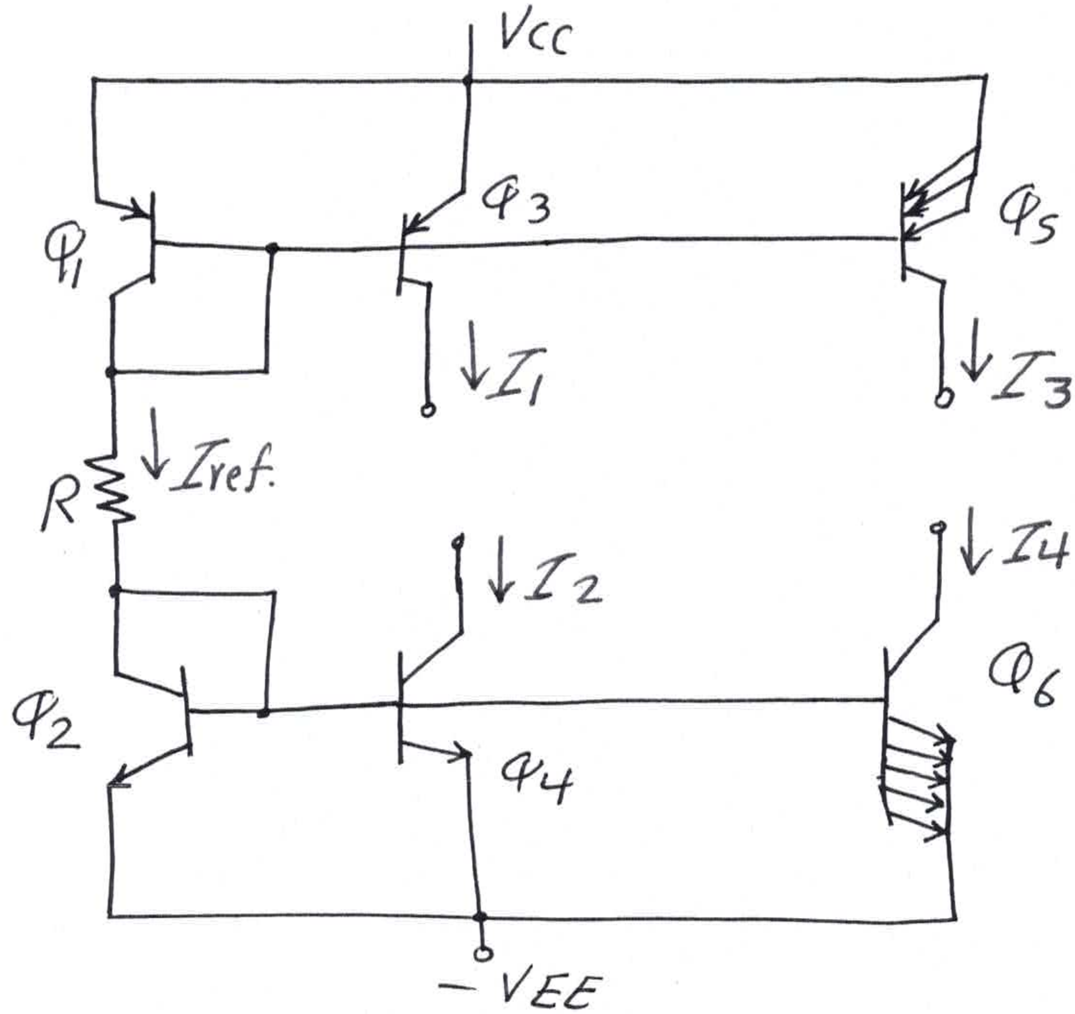
$$I_o = \frac{\beta}{1+\beta} I_E \quad , \quad I_{ref} = \frac{2+\beta}{1+\beta} I_E$$

$$\therefore \quad \boxed{I_o = \frac{I_{ref}}{1 + \frac{2}{\beta}}} \quad , \quad I_{ref} = \frac{V_{EE} - V_{EB}}{R}$$

oR

$$\boxed{I_o = \frac{1}{1 + \frac{2}{\beta}} \; \frac{V_{EE} - V_{EB}}{R}}$$

Generation of a number of constant currents:-



* $I_1 = I_{ref}$ $(\beta \ggg)$

* $I_2 = I_{ref}$

* $I_3 = 3 I_1 = 3 I_{ref}.$

* $I_4 = 5 I_2 = 5 I_{ref}$

* $I_{ref} = \dfrac{V_{CC} + V_{EE} - V_{BE_2} - V_{EB1}}{R}$

Improved Current Source Circuit :-

Performance Parameters needed:-

* I_o independent of β
* r_o (output resistance) is very high.

To obtain these parameters (improve C.S),

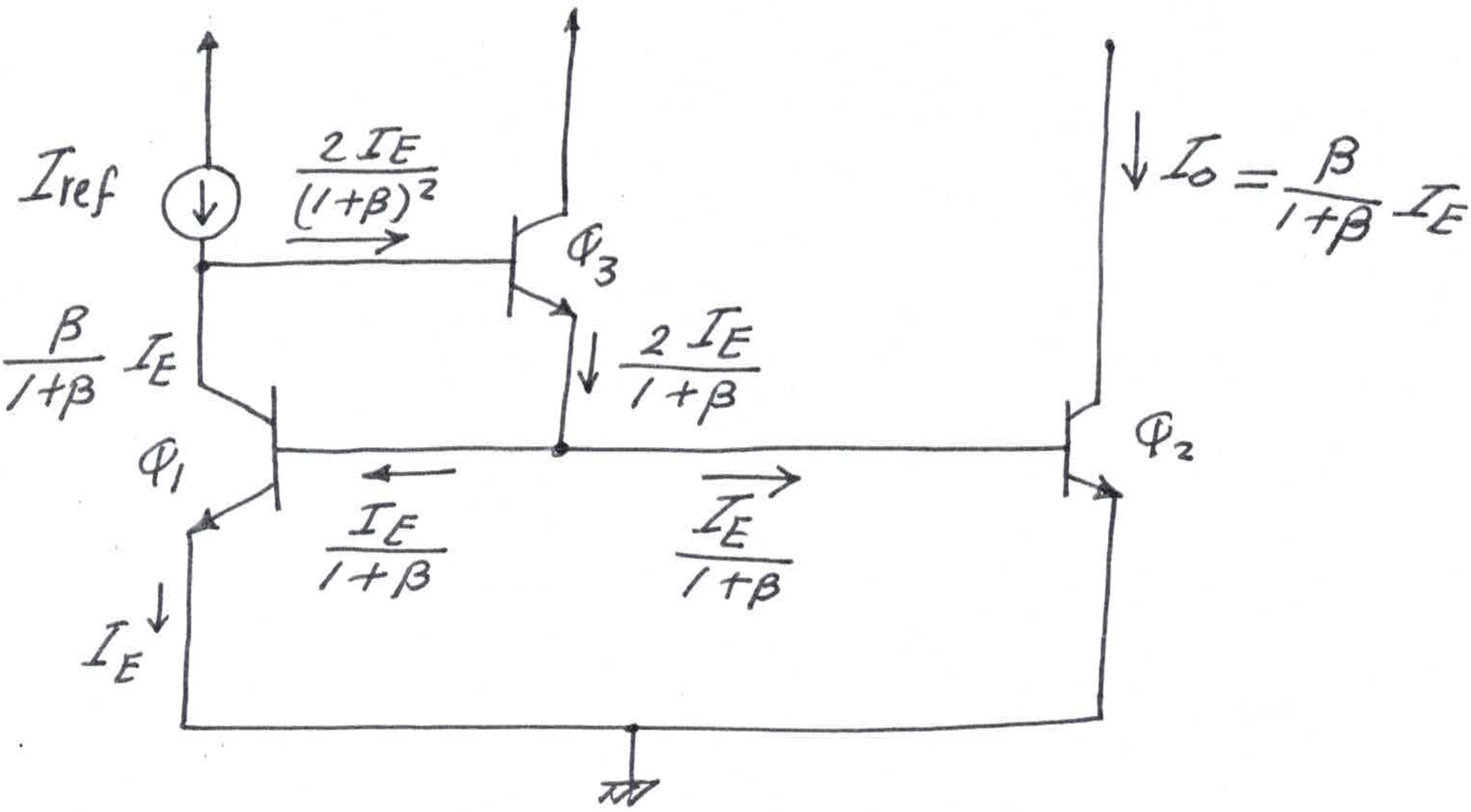
the following Circuits will be used:-

[1] Current mirror with base-current Compensation.

[2] Wilson Current Source.

[3] Widler Current Source.

1 Current mirror with base-current Compensation :-



$$* \quad I_{ref} = \frac{\beta}{1+\beta} I_E + \frac{2I_E}{(1+\beta)^2}$$

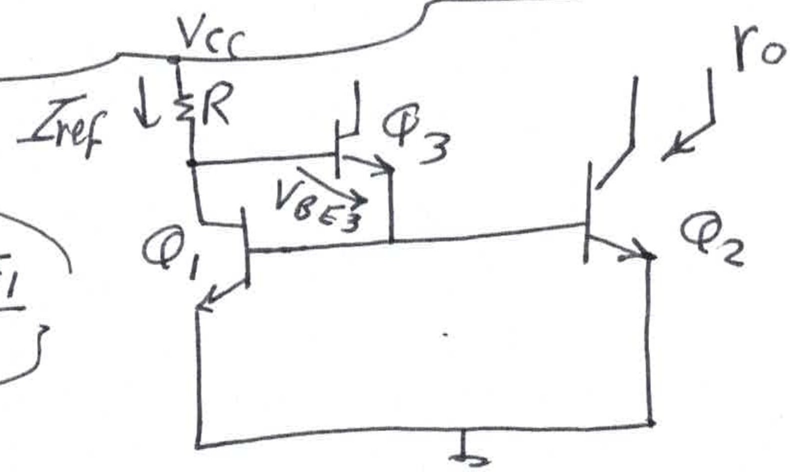
$$I_{ref} = \left[\frac{\beta}{1+\beta} + \frac{2}{(1+\beta)^2}\right] I_E \rightarrow \boxed{1}$$

$$* \quad I_o = \frac{\beta}{1+\beta} I_E \rightarrow \boxed{2}$$

$\boxed{2} \div \boxed{1}$ $\quad \therefore \quad \frac{I_o}{I_{ref}} = \frac{\frac{\beta}{\cancel{1+\beta}}}{\frac{\beta}{\cancel{1+\beta}} + \frac{2}{(1+\beta)^{\cancel{2}}}}$

$$\frac{I_o}{I_{ref}} = \frac{\beta}{\beta + \frac{2}{1+\beta}} = \frac{1}{1 + \frac{2}{\beta+\beta^2}}$$

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



$$I_{ref} = \frac{V_{CC} - V_{BE3} - V_{BE1}}{R}$$

$$\therefore I_o = \frac{1}{1+\frac{2}{\beta^2}} \cdot \frac{V_{CC} - V_{BE3} - V_{BE1}}{R}$$

Then, the error due to finite (β) has been reduced from ($\frac{2}{\beta}$) to ($\frac{2}{\beta^2}$).

Note $\frac{I_o}{I_{ref}} = \frac{1}{1+\frac{2}{\beta^2}} \cong 1$

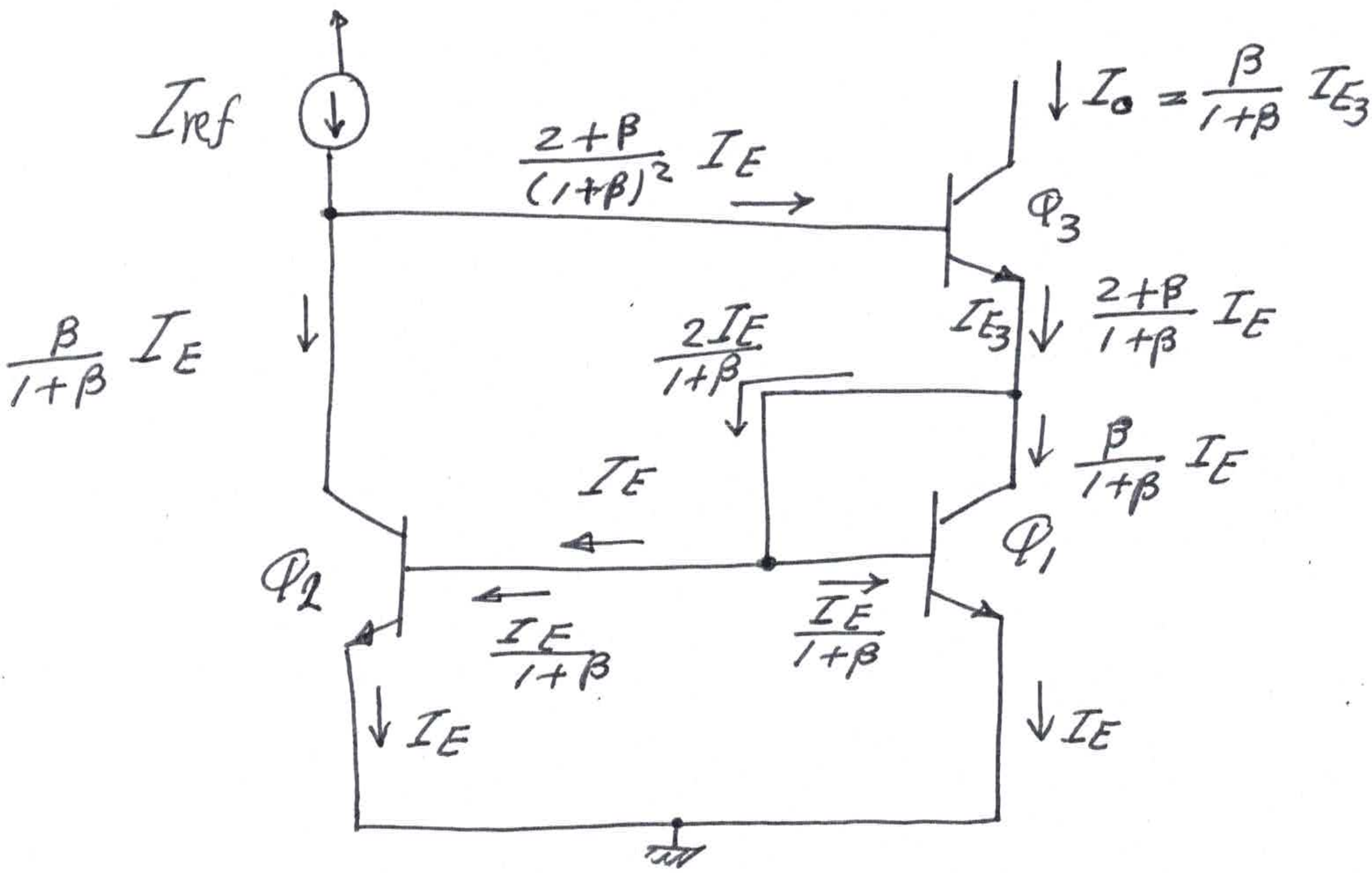
$$r_o = r_{o2} = \frac{V_A}{I_o}$$

[2] Wilson Current Source :-

Advantages :-

[1] Base_current Compensation.

[2] Increasing the output resistance.



$$* \quad I_o = \left(\frac{\beta}{1+\beta}\right) I_{E_3} = \frac{\beta}{1+\beta} \left(\frac{2+\beta}{1+\beta} I_E\right)$$

$$I_o = \frac{\beta^2+2\beta}{(1+\beta)^2} I_E \longrightarrow \boxed{1}$$

$$* \quad I_{ref} = \frac{\beta}{1+\beta} I_E + \frac{2+\beta}{(1+\beta)^2} I_E$$

$$I_{ref} = \left[\frac{\beta}{1+\beta} + \frac{2+\beta}{(1+\beta)^2}\right] I_E \longrightarrow \boxed{2}$$

$\boxed{1} \div \boxed{2}$

$$\therefore \frac{I_o}{I_{ref}} = \frac{\dfrac{\beta^2+2\beta}{(1+\beta)^2}}{\dfrac{\beta}{1+\beta} + \dfrac{2+\beta}{(1+\beta)^2}}$$

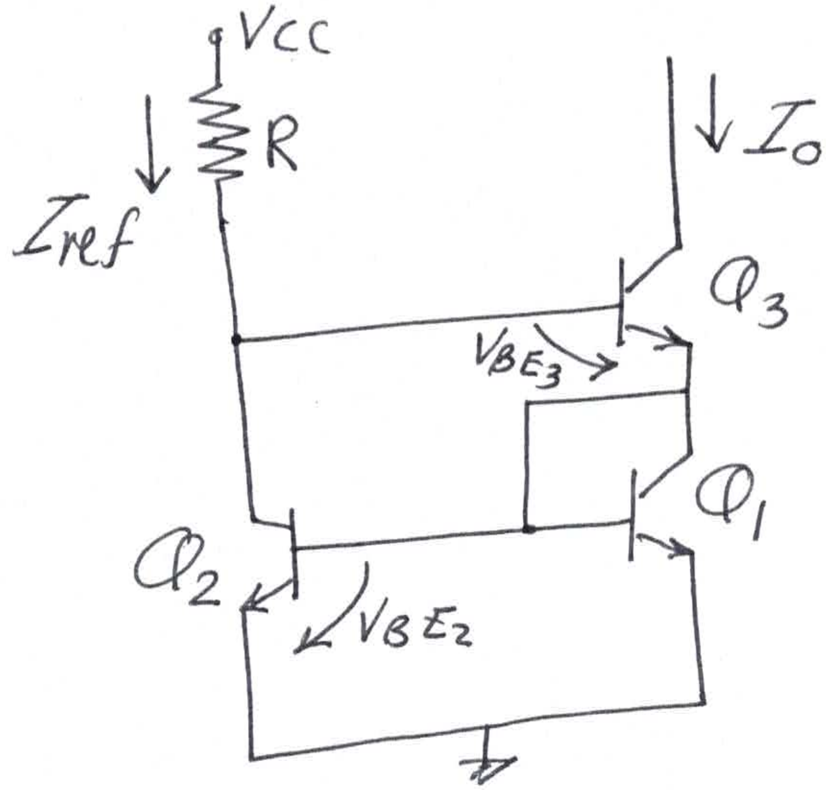
$$= \frac{\beta^2+2\beta}{\beta(1+\beta)+2+\beta} = \frac{(\beta^2+2\beta)}{(\beta^2+2\beta)+2}$$

$$\frac{I_o}{I_{ref}} = \frac{1}{1+\dfrac{2}{\beta^2+2\beta}}$$

$$\therefore \boxed{I_o = \frac{I_{ref}}{1+\dfrac{2}{\beta^2+2\beta}}}$$

The error due to finite (β) has been reduced from $\left(\frac{2}{\beta}\right)$ to $\left(\frac{2}{\beta^2+2\beta}\right)$

IF (Iref) is drawn from (Vcc) supply



$$I_{ref} = \frac{V_{CC} - V_{BE3} - V_{BE2}}{R}$$

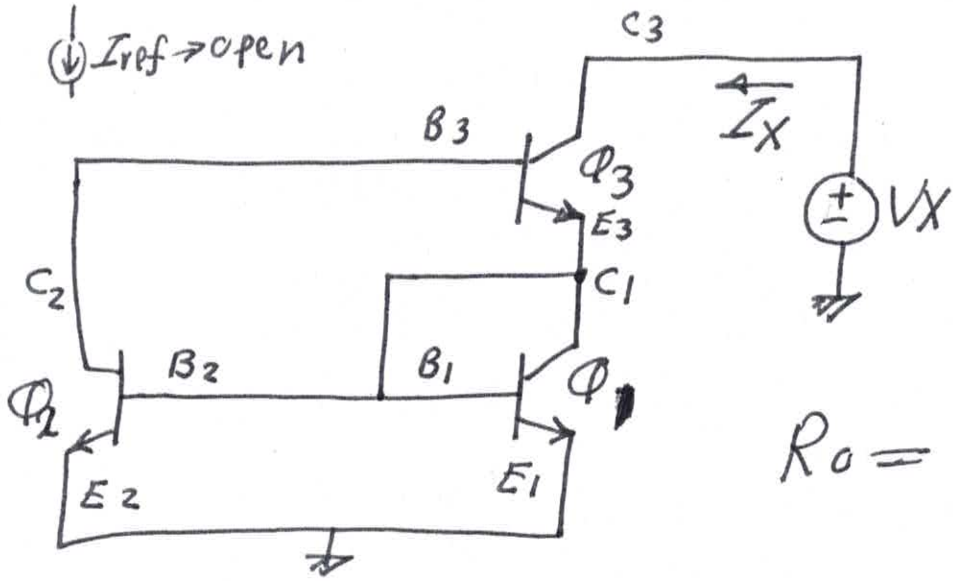
$$\therefore \quad I_o = \frac{1}{1 + \frac{2}{\beta^2 + 2\beta}} \cdot \frac{V_{CC} - V_{BE3} - V_{BE2}}{R}$$

and

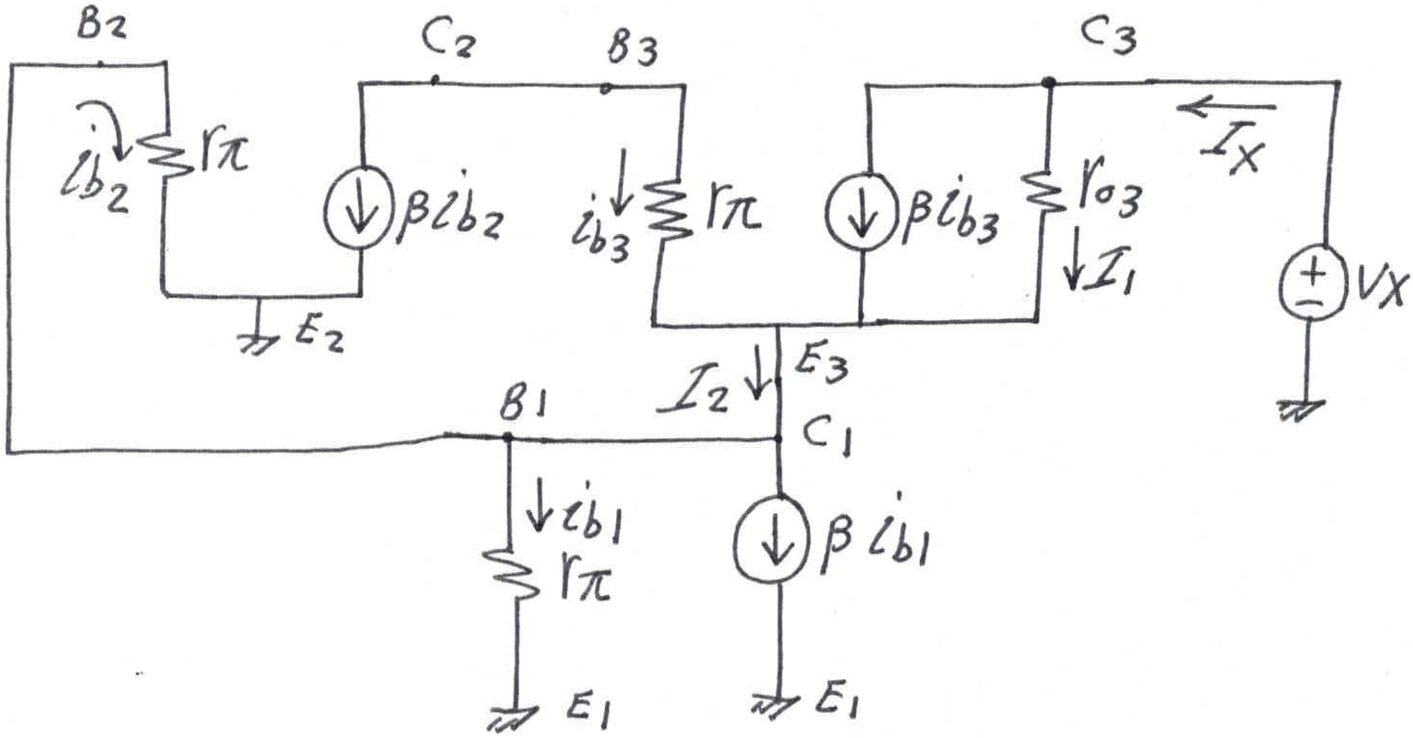
$$R_o = \frac{\beta r_o}{2} = \frac{\beta r_{o3}}{2}$$

$$r_{o3} = \frac{V_A}{I_o}$$

Wilson current - Source output Resistance:-



$$R_o = \frac{V_X}{I_X}$$



Q_1 and Q_2 are identical.

$$\therefore \boxed{i_{b1} = i_{b2}} = i_b$$

* $\beta i_{b2} = -i_{b3}$

$$\boxed{i_{b3} = -\beta i_{b2} = -\beta i_b}$$

$* \quad I_2 = \beta i_{b1} + i_{b1} + i_{b2}$

$= (1+\beta) i_{b1} + i_{b2} \quad , \; i_{b1} = i_{b2} = i_b$

$$\boxed{I_2 = [2+\beta] i_b}$$

$* \quad I_1 + \beta i_{b3} + i_{b3} = I_2$

$I_1 + (1+\beta)(-\beta i_b) = I_2$

$I_1 = \beta(1+\beta) i_b + \overbrace{(2+\beta) i_b}^{I_2}$

$I_1 = [\beta + \beta^2 + 2 + \beta] i_b$

$$\boxed{I_1 = [\beta^2 + 2\beta + 2] i_b}$$

$* \quad I_X = I_1 + \beta i_{b3} = I_1 + \beta(-\beta i_b)$

$I_X = I_1 - \beta^2 i_b = (\beta^2 + 2\beta + 2) i_b - \beta^2 i_b$

$$\boxed{I_X = (2 + 2\beta) i_b}$$

$* \quad V_X = V_{r_{o3}} + V_{B1} = I_1 r_{o3} - i_{b1} r_\pi$

$V_X = (\beta^2 + 2\beta + 2) i_b \, r_{o3} - i_b r_\pi$

$$\boxed{V_X = [(\beta^2 + 2\beta + 2) r_{o3} - r_\pi] i_b}$$

$$\therefore R_o = \frac{V_X}{I_X} = \frac{(\beta^2+2\beta+2)\, r_{o3} - r_\pi}{2+2\beta}$$

$$(\beta^2+2\beta+2)\, r_{o3} \gg r_\pi$$

$$R_o \cong \frac{\beta^2+2\beta+2}{2+2\beta}\, r_{o3}$$

$$\beta^2 \gg 2\beta+2$$

and $2\beta \gg 2$

$$\therefore R_o \cong \frac{\beta^2}{2\beta}\, r_{o3}$$

$$R_o \cong \frac{\beta\, r_{o3}}{2} = \frac{\beta\, r_o}{2}$$

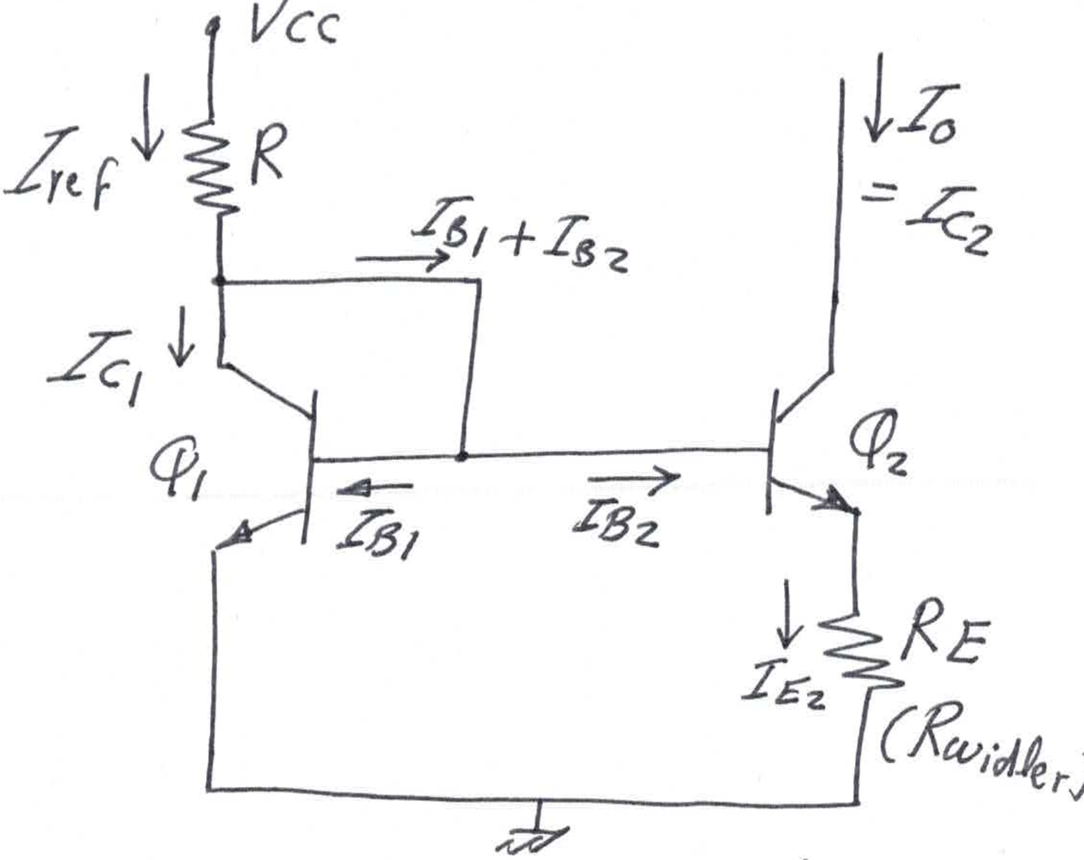
For example, if $\beta = 100$, $r_o = 50\,k\Omega$

then, $R_o = 2.5\,M\Omega$

$\therefore$ wilson C.S output resistance is very large

3 Widler Current Source :-

Advantage very high o/p Resistance (4 – 6 MΩ)



Q_1 and Q_2 are matched (identical)

but $V_{BE1} \neq V_{BE2}$

$$I_{ref} = I_{C1} + I_{B1} + I_{B2}$$

$$I_{ref} = I_{C1} + \frac{I_{C1}}{\beta} + \frac{I_{C2}}{\beta}$$

but $V_{BE1} > V_{BE2}$

$\therefore \; I_{C1} > I_{C2}$

$\therefore \quad \frac{I_{C1}}{\beta} > \frac{I_{C2}}{\beta}$, Neglect $\frac{I_{C2}}{\beta}$

$$\therefore \quad I_{ref.} \cong I_{C1} + \frac{I_{C1}}{\beta} = (1 + \frac{1}{\beta}) I_{C1}$$

$$I_{ref} \cong \frac{1+\beta}{\beta} I_{C1}$$

$$\therefore \quad I_{C1} = \frac{\beta}{1+\beta} I_{ref.} = \frac{\beta}{1+\beta} \left(\frac{V_{CC} - V_{BE1}}{R} \right)$$

$$\boxed{I_{C1} \cong \frac{V_{CC} - V_{BE1}}{R}} \quad \boxed{1}$$

* $V_{BE1} = V_{BE2} + I_{E_2} R_E$

$$\therefore \quad \underbrace{V_{BE1} - V_{BE2}}_{\downarrow} = (I_{B2} + I_{C2}) R_E$$

$$\Delta V_{BE} = \left(\frac{I_{C2}}{\beta} + I_{C2} \right) R_E = (\frac{1}{\beta} + 1) I_{C2} R_E$$

$$\therefore \quad \boxed{\Delta V_{BE} \cong I_{C2} R_E} \quad \boxed{2}$$

* But $\quad I_{C1} = I_S \, e^{V_{BE1}/V_T}$

$$I_{C2} = I_S \, e^{V_{BE2}/V_T}$$

$$\therefore \frac{I_{C1}}{I_{C2}} = e^{\frac{V_{BE1} - V_{BE2}}{V_T}}$$

$$\ln\left(\frac{I_{C1}}{I_{C2}}\right) = \frac{V_{BE1} - V_{BE2}}{V_T} = \frac{\Delta V_{BE}}{V_T}$$

$$\therefore \boxed{\Delta V_{BE} = V_T \ln\left(\frac{I_{C1}}{I_{C2}}\right)} \quad \boxed{3}$$

From $\boxed{2}$, $\boxed{3}$

$$\therefore I_{C2} R_E = V_T \ln\left(\frac{I_{C1}}{I_{C2}}\right)$$

but $I_{C1} = I_{ref}$, $I_{C2} = I_o$

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

$$I_o = \frac{V_T}{R_E} \ln\left(\frac{I_{ref}}{I_o}\right)$$ مهم

$(I_o < I_{ref})$

where:- R_E is the Widler Resistance.

* IF I_o given → substitute to Find R_E
* IF R_E given → solve For I_o using trial and error

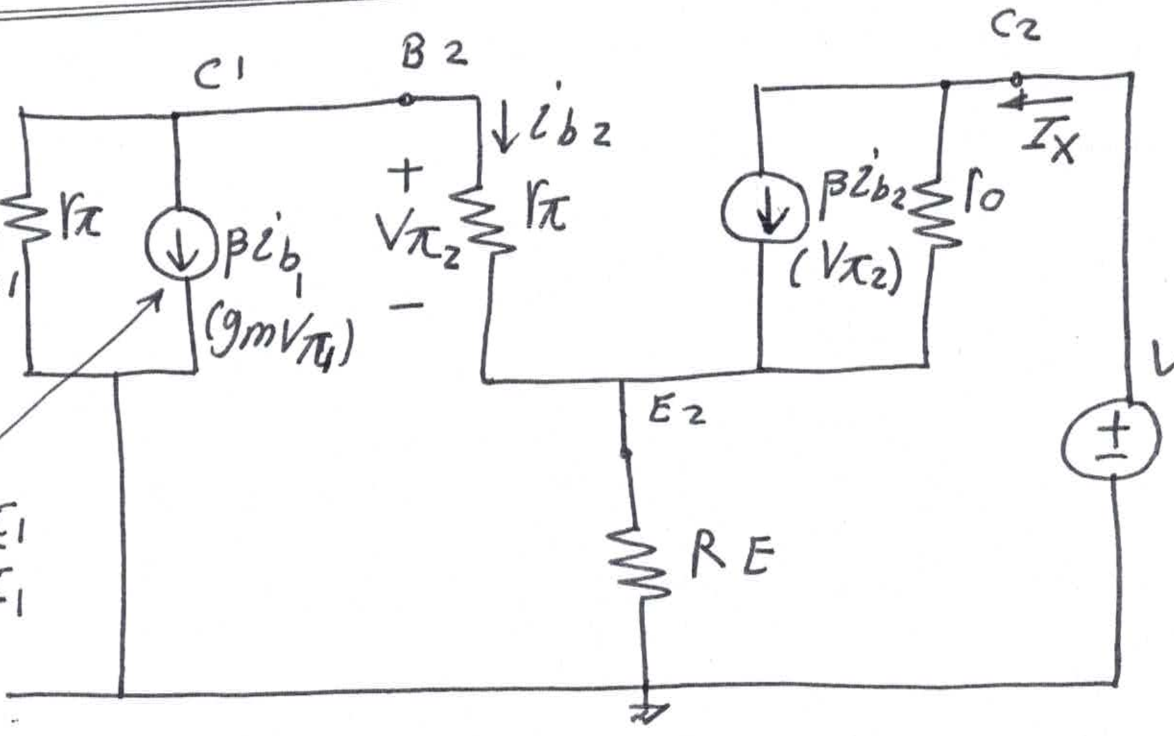
Widler output Resistance (R_o) :-

$$\boxed{R_o = (1 + g_m \grave{R}_E)\, r_o}$$ مهم

$\grave{R}_E = R_E \parallel r_\pi$ $\Rightarrow$ مهم

* Widler o/p Resistance is very high (4 – 6 MΩ)

Prove



$$R = \frac{V_{\pi_1}}{g_m V_{\pi_1}}$$

$$R = \frac{1}{g_m}$$

* $\frac{1}{g_m} \parallel r_\pi \cong \frac{1}{g_m}$ since $\frac{1}{g_m} << r_\pi$

* $\frac{1}{g_m} + r_\pi \cong r_\pi$