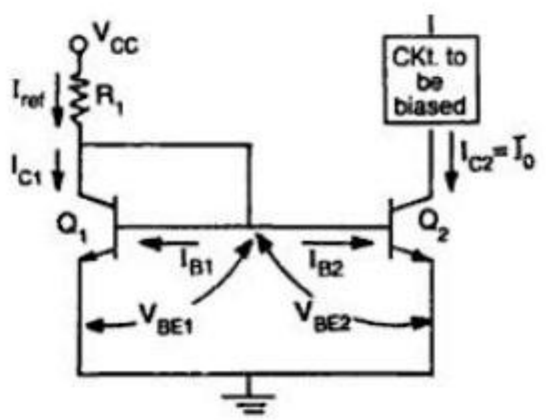
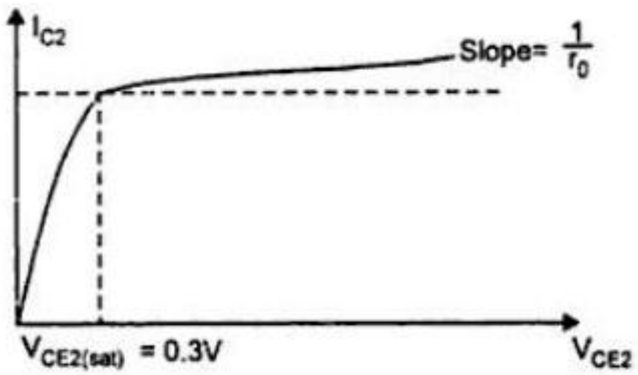
Constant current source (Current Mirror)

A constant current source makes use of the fact that for a transistor in the active mode of operation, the collector current is relatively independent of the collector voltage. In the basic circuit shown in fig 1 and collector characteristics of a CE Transistor as in fig.2



Current mirror circuit



Current source output current characteristics

Transistors Q_1&Q_2 are matched as the circuit is fabricated using IC technology. Base and emitter of Q_1& Q_2 are tied together and thus have the same VBE. In addition, transistor Q_1 is connected as a diode by shorting its collector to base. The input current I_{ref} flows through the diode connected transistor Q_1 and thus establishes a voltage across Q_1. This voltage in turn appears between the base and emitter of Q_2 .Since Q_2 is identical to Q_1, the emitter current of Q_2 will be equal to emitter current of Q_1 which is approximately equal to I_{ref}. As long as Q_2 is maintained in the active region ,its collector current I_{C2}=I_o will be approximately equal to I_{ref} . Since the output current Io is a reflection or mirror of the reference current I_{ref}, the circuit is often referred to as a current mirror.

Analysis:

The collector current I_{C1} and I_{C2} for the transistor Q_1 and Q_2 can be approximately expressed as

$$I_{C1}(t) = \alpha\, I_{ES} e^{V_{BE1}/V_T} \quad \text{------------------------------} \ (1)$$

$$I_{C2}(t) = \alpha\, I_{ES} e^{V_{BE2}/V_T} \quad \text{------------------------------} \ (2)$$

Where I_{ES} is reverse saturation current in emitter junction and VT is temperature equivalent of voltage.

From equation (1) & (2)

Since $V_{BE1}=V_{BE2}$ we obtain $I_{C2}=I_{C1}=I\backslash_{C}=I_{O}$

Also since both the transistors are identical, $I_{C1}= I_{C2}$

KCL at the collector of Q_1 gives

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

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

$$= I_{C1} + \frac{I_{C1}}{\beta} + \frac{I_{C2}}{\beta} = I_{C1} + 2\frac{I_{C1}}{\beta} \quad \text{When } I_{C1} = I_{C2} = I_C = I_o \quad \text{---------------} \ (4)$$

Solving Eq (4)

$$I_{ref} = (V_{CC} - V_{BE(ON)})/R$$

$$I_{ref} = I_{C1} + 2\frac{I_{C1}}{\beta} = I_{C1}\left(1 + \frac{2}{\beta}\right)$$

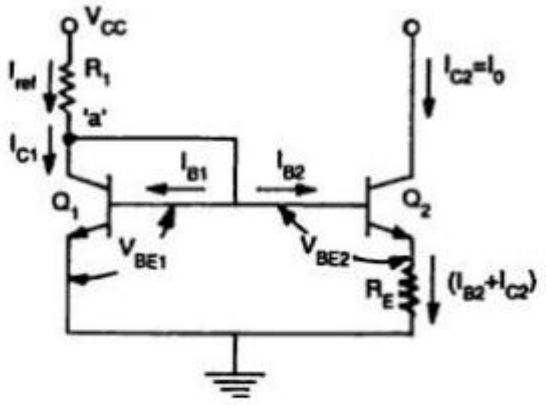
$$I_C = I_{C1} = I_{C2} = \frac{I_{ref}}{1+\frac{2}{\beta}} = \frac{\beta}{\beta+2}\,(V_{CC} - V_{BE(ON)})/R \quad \text{-----------------} \ (5)$$

$$I_0 = I_{ref}$$

From Eq.5 for β/ [β +1] >>1, is almost unity and the output current I0 is equal to the reference current, ref which for a given R_1 is constant. Typically I_o varies by about 3% for 50 ≤ β ≤200.

The circuit however operates as a constant current source as long as Q_2 remains in the active region.

Widlar current source:



Widlar current source

Widlar current source which is particularly suitable for low value of currents. To overcome the limitations of constant current source connect R_E to the emitter terminal of Q_2.The circuit differs from the basic current mirror only in the resistance R_E that is included in the emitter lead of Q_2. It can be seen that due to R_E the base-emitter voltage V_{BE2} is less than VBE1 and consequently current Io is smaller than I_{C1}

The ratio of collector currents I_{C1}&I_{C2} using

$$\frac{I_{C1}}{I_{C2}} = e^{\frac{V_{BE1}-V_{BE2}}{V_T}} \qquad \textbf{(1)}$$

Taking natural logarithm of both sides, we get

$$V_{BE1} - V_{BE2} = V_T \ln \frac{I_{C1}}{I_{C2}} \qquad \text{----- (2)}$$

Writing KVL for the emitter base loop

$$V_{BE1}=V_{BE2}+(I_{B2}+I_{C2})R_E \qquad \text{----------------(3)}$$

Or $$V_{BE1}-V_{BE2}=(1/\beta+1)I_{C2}R_E \qquad \text{-----------(4)}$$

From eqn. (2) & (4) we obtain

$$V_T \ln \frac{I_{C1}}{I_{C2}} = (1/\beta+1)\, I_{C2}R_E \qquad \text{---------- (5)}$$

A relation between I_{C1} and the reference current I_{ref} is obtained by writing KCL at the collector point of Q1

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

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

Neglecting I_{C2}/β,

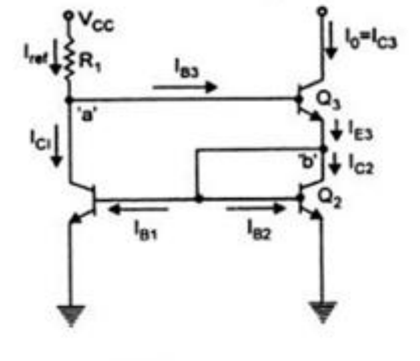
$I_{ref} = I_{C1}\,(1 + 1/\beta)$

$I_{ref} = [\,Vcc - V_{BE}\,]/R_1$

When $\beta >> 1$, $I_{C1} = I_{ref}$

Wilson current source:

The Wilson current source shown in figure



Wilson current source

It provides an output current I_0 which is very nearly equal to V_{ref} and also exhibits a very high output resistance.

Analysis

Since $V_{BE1}=V_{BE2}$

$I_{C1}=I_{C2}$ and $I_{B1}=I_{B2}=I_B$

At node 'b'

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

I_{E3} is equal to

$I_{E3}=I_{C3}+I_{B3}=I_{C3}(1+1/\beta)$ ------------------ (2)

From (1) and (2)

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

From Eqn. (1) & (2) we obtain

$I_{C3}=I_O=I_{C2}(\beta \square 2)/(\beta+1)=I_{C1}(\beta \square 2)/(\beta+1)$ Since $I_{C1}=I_{C2}$

At node 'a' $I_{ref}=I_{C1}+I_{B3}=\frac{\beta+1}{\beta+2}I_O+\frac{I_O}{\beta}=$

$I_{ref}=\frac{\beta^2+2\beta+2}{\beta^2+2\beta}I_O$ and $I_{ref}=\frac{V_{cc}-2V_{BE}}{R_1}$; $I_O-I_{ref}=\frac{2}{\beta^2+2\beta+2}$ I ref is very small for modest β.

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Current sources as Active loads

The current source can be used as an active load in both analog and digital IC's. The active load realized using current source in place of the passive load (i.e. a resistor) in the collector arm of differential amplifier makes it possible to achieve high voltage gain without requiring large power supply voltage. The active load so achieved is basically R0 of a PNP transistor.