BJT Biasing Cont.

- Biasing for DC Operating Point Stability
- BJT Bias Using Emitter Negative Feedback
- Single Supply BJT Bias Scheme
- Constant Current BJT Bias Scheme
- “Rule of Thumb” BJT Bias Design
Simple Base Biasing Schemes

What's wrong with these schemes?
Another Simple Biasing Scheme

Is this scheme any better? If it is, why?
Biasing for Operating Point Stability

A practical biasing scheme must be insensitive to changes in transistor $\beta$ and operating temperature! Negative feedback is one solution.

Consider the circuit:

And make the following observations. Assume active mode operation:

$$V_{CE} > 0.2\,V.$$  

Then:

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

$$V_{BE} = V_B - R_E I_E$$
Given the (DC bias) equations:

\[ I_C \approx I_S e^{\frac{V_{BE}}{V_T}} \]

\[ V_{BE} = V_B - R_E I_E = V_B - R_E \frac{I_C}{\alpha} \]

Assume: \( V_{BE} = 0.7 \) V

Let: \( V_B, V_{CC} \) and \( I_C \) be specified;

Compute: \( R_E \) to obtain \( I_C \):

\[ R_E = \alpha \frac{V_B - V_{BE}}{I_C} = \alpha \frac{V_B - 0.7}{I_C} \]

Basic relationships:

\[ I_E = I_B + I_C = (\beta + 1) I_B \]

\[ I_E = \frac{(\beta + 1)}{\beta} I_C = \frac{1}{\alpha} I_C \]
Negative Feedback via $R_E$

- Negative feedback makes the collector current insensitive to $V_{BE}$, $I_S$, and $\beta$.
- If $I_C$ increases – due to an increase in $I_S$ then $V_{BE}$ will decrease; thus, limiting the magnitude of the change in $I_C$.
- The equations that must be satisfied simultaneously are:

\[
I_C = I_S e^{\frac{V_{BE}}{V_T}} \quad \text{and} \quad V_{BE} = V_B - R_E \frac{I_C}{\alpha} = V_B - \frac{1}{\alpha} R_E I_C
\]

$I_S$ insensitivity

If $I_S \uparrow \Rightarrow I_C \uparrow \Rightarrow \text{when } I_C \uparrow \Rightarrow V_{BE} \downarrow \Rightarrow I_S \text{ insensitivity}$

If $R_E = 0$ then $V_B = V_{BE} \Rightarrow \text{feedback is absent}$
Negative Feedback via $R_E$

\[ I_C = I_S e^{\frac{V_{BE}}{V_T}} \]

and

\[ V_{BE} = V_B - R_E \frac{I_C}{\alpha} = V_B - \frac{1}{\alpha} R_E I_C \]

**$\beta$ insensitivity**

\[ I_C = \frac{\beta (V_B - V_{BE})}{(\beta + 1) R_E} = \frac{V_B - V_{BE}}{R_E} \]

**$V_{BE}$ insensitivity**

\[ I_C = \alpha \frac{V_B - V_{BE}}{R_E} \]

if $V_B >> V_{BE}$  \(\Rightarrow\)  $I_C \approx \alpha \frac{V_B}{R_E}$
Scilab Analysis of $I_C$ Insensitivity to $I_S$

Simultaneous equations:

\[ I_C = I_S e^{\frac{V_{BE}}{V_T}} \]

or:

\[ \alpha \frac{V_B - V_{BE}}{R_E} = I_S e^{\frac{V_{BE}}{V_T}} \]

Let $R_E = 4k \ \Omega$ and $V_B = 4.7V$ (want $V_B >> V_{BE}$)

If we plot the exponential function and the straight line function, the solution values of $I_C$ and $V_{BE}$ for the circuit occur at their intersection.
Scilab Program

//Calculate and plot npn BJT bias characteristic
beta=100;
alpha=beta/(beta+1);
VsubT=0.025;
VTinv=1/VsubT;
VBB=4.7;
Re=4;
vBE=0.0:0.01:1;
iCline=alpha*(VBB-vBE)/Re;//mA.
plot(vBE,iCline);
iC=0.01:0.01:2;//mA!
IsubS =1E-16;//mA.
for k= 1:1:8
   IsubS=10*IsubS;
vBE2=VsubT*log(iC/IsubS);
plot(vBE2,iC);//Current in mA.
end

\[ I_C = \alpha \frac{V_B - V_{BE}}{R_E} \]

\[ V_{BE} = V_T \ln \frac{I_C}{I_S} \]
$I_C \approx 0.1 \text{ mA}$

$I_C = \alpha \frac{V_B - V_{BE}}{R_E}$

$\Delta I_C \approx 0.1 \text{ mA}$

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

Insensitive to $I_S$!
Insensitivity to Beta

\[ R_E = \alpha \frac{V_B - 0.7}{I_C} \]

Example: \( \beta = 100 \)

\[ V_B = 4.7 \, V \]
\[ I_C = 1 \, mA \]
\[ \alpha = \frac{100}{101} \approx 0.99 \]
\[ R_E = 0.99 \cdot \frac{4.7 - 0.7}{10^{-3}} \]
\[ R_E \approx 4000 \, \Omega \]

Writing \( I_C \) as a function of \( \beta \):

\[ I_C = \alpha \frac{V_B - 0.7}{R_E} = \frac{\beta}{\beta + 1} \cdot 10^{-3} \, A \]

Assume: \( 100 \leq \beta \leq 200 \)

\[ \frac{100}{101} \cdot 10^{-3} = 0.990 \, mA < I_C < \frac{200}{201} \cdot 10^{-3} = 0.995 \, mA \]

CONCLUSION:

\( I_C \) is insensitive to changes in \( \beta \)!
Non-zero Base Resistance

\[ V_B = I_B R_B + V_{BE} + (\beta + 1) I_B R_E \]

\[ I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1) R_E} \]

\[ I_C = \beta I_B = \frac{\beta}{R_B + (\beta + 1) R_E} (V_B - V_{BE}) \]

\[ I_E = (\beta + 1) I_B \]

If \( R_B \ll (\beta + 1) R_E \)

\[ I_C = \beta I_B \approx \frac{\beta}{\beta + 1} \frac{(V_B - V_{BE})}{R_E} = \alpha \frac{(V_B - V_{BE})}{R_E} \]

\[ V_{BE} = V_B - \frac{1}{\alpha} R_E I_C \]

If \( R_B \gg (\beta + 1) R_E \)

\[ I_C = \beta I_B \approx \frac{\beta}{R_B} (V_B - V_{BE}) \]

Effect of Feedback is minimized!
Biasing for Operating Point Stability – Quick Review

What is the purpose $R_E$?

What does $R_B$ represent?

What is the condition on the value of $V_B$?

What is the condition on the value of $R_E$?

What is our rule of thumb for achieving $x >> y$?
Observations

- Emitter feedback stabilizes base voltage source bias.
- To reduce the sensitivity of $I_C$ to $V_{BE}$, choose $V_B \gg V_{BE}$.
- $R_B \neq 0$, emitter feedback stabilization works well if $R_B$ is “not too large,” i.e.

$$R_B \ll (\beta + 1) R_E$$

Ideal rule of thumb (if possible):

$$R_B \leq \frac{1}{10} (\beta + 1) R_E \quad \text{or} \quad R_B = \frac{1}{10} (\beta + 1) R_E$$

Let $\beta + 1 = 100$ 

$$R_B = \frac{100}{10} R_E = 10 R_E$$
Emitter-Feedback Bias Design

Voltage bias circuit

Single power supply version
Thevenin Equivalent

\[ R_{Th} = R_B = R_1 || R_2 \]

\[ V_{Th} = V_B = \frac{R_2}{R_1 + R_2} V_{CC} \]

\[ I_B \ll I_1 \ll I_C \]
Emitter-Feedback Bias Design

What is the purpose of $R_E$?

What is the purpose of $R_1$ & $R_2$?

What happened to $R_B$?

How are $V_B$ & $V_{CC}$ related?

What is the condition on the values of $R_1$, $R_2$ & $R_E$?

What is the condition on the values of $I_I$, $I_B$ & $I_C$?
Using Thevenin Equivalent

Let's assume that $I_1 >> I_B$ & $I_1 << I_C$. Furthermore assume $V_{CC}$, $V_B$ & $R_B$ are independently specified. Solve for resistors $R_1$ & $R_2$.

\[
R_B = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} \quad (1)
\]

\[
V_B = \frac{R_2}{R_1 + R_2} V_{CC} \quad (2)
\]

Can $V_{CC}$, $V_B$ & $R_B$ be independently specified; e.g.?

\[
R_B = \frac{1}{10} (\beta + 1) R_E
\]

\[
V_B = 10 V_{BE}
\]
Can $V_{CC}$, $V_B$ & $R_B$ be independently specified; e.g.?

$V_B = 10 V_{BE}$

$R_B = \frac{1}{10} (\beta + 1) R_E$

NO! Independently specify $V_{CC}$, $V_B$ & $I_C$

s.t. $R_B << (\beta + 1) R_E$ & $V_B >> V_{BE}$
1st “Rule of Thumb” for Single Supply Biasing

1. Choose $R_T = R_1 + R_2$ so that $I_1 >> I_B$ & $I_1 << I_C$, i.e. $I_1$ is about $1/10$ of the desired $I_C$ & $I_B$ is ignored when compared to $I_1$:

$$I_1 = \frac{V_{CC}}{R_T} = \frac{I_C}{10} \quad R_T = R_1 + R_2 = 10 \frac{V_{CC}}{I_C}$$

2. Use a voltage divider to give the desired base voltage $V_B$ and solve for $R_1$ and $R_2$:

$$R_2 = R_T \frac{V_B}{V_{CC}}$$

$$R_1 = R_T - R_2 = R_T \left(1 - \frac{V_B}{V_{CC}}\right)$$

3. Calculate $R_B$: $R_B = R_1 || R_2$
An Unavoidable Design Tradeoff

With $V_{CC}$, $I_C$ & $V_B$ specified, 3 design constraints, i.e.

- $R_B \ll (\beta + 1) R_E$
- $V_B \gg V_{BE}$
- $I_1 \ll I_C$ also $I_1 \gg I_B$

where: $V_{CC} = V_{Rc} + V_{CE} + V_{RE}$

- **TRADEOFF**
  - Increase $V_{RC}$ and/or $V_{RE} \Rightarrow$ Reduce $V_{CE}$ ($V_{CC}$ fixed)
  - $V_{RC}$ too large $\Rightarrow$ possible saturation & reduced operating range (i.e. $V_{CE} \rightarrow 0.2 \, V$ or smaller).
  - $V_{RC}$ too small $\Rightarrow$ possible cutoff & reduced operating range (i.e. $I_C \rightarrow$ small or zero).

- **NEED A COMPROMISE!**

$$V_{Re} = V_B - V_{BE}$$
2nd Useful “Rule of Thumb”

“1/3, 1/3, 1/3 Rule”

\[
\begin{align*}
V_{R_E} &= \frac{V_{CC}}{3} \\
V_{R_C} &= I_C R_C = \frac{V_{CC}}{3} \\
V_{CE} &= \frac{V_{CC}}{3}
\end{align*}
\]

where \( V_{CC} = V_{R_C} + V_{R_E} + V_{CE} \) & \( V_B = \frac{R_2}{R_T} V_{CC} \)

If \( V_B \gg V_{BE} \implies V_{CC} \approx V_{R_C} + V_{CE} + V_B \)

Design Equations

\[
\begin{align*}
R_C &= \frac{V_{R_C}}{I_C} = \frac{V_{CC}}{3 I_C} \\
R_E &= \frac{V_{R_E}}{I_E} = \frac{V_{CC}}{3 I_E} = \frac{\alpha V_{CC}}{3 I_C} \\
V_{R_E} &= V_{CC} \frac{R_2}{R_T} - V_{BE} = \frac{V_{CC}}{3}
\end{align*}
\]

\[
\begin{align*}
I_1 &= \frac{I_C}{10} \approx \frac{V_{CC}}{R_T} \\
R_2 &= R_T \frac{V_B}{V_{CC}} \approx \frac{1}{3} R_T \\
R_1 &= R_T \left(1 - \frac{V_B}{V_{CC}}\right) \approx \frac{2}{3} R_T
\end{align*}
\]

\( V_B = V_{BE} + V_{R_E} \approx I_1 R_2 \)

\( V_{BE} = 0.7 \, V \)

If \( V_B \gg V_{BE} \implies V_{R_E} \approx V_B \)
**Constant Emitter Current Bias**

Specified: $V_{CC}$ & $I_E$
Constant Emitter Current Bias

The current mirror is used to create a current source:

1. A BJT collector is the current source:
   \[
   I_C = I_S e^{\frac{V_{BE}}{V_T}}
   \]

2. A diode-connected transistor sets the current:
   \[
   I_{REF} = \frac{V_{CC} - V_{BE1}}{R_{ref}}
   \]
   \[
   I_{REF} = I_{C1} + I_{B1} + I_{B2} \approx I_{C1} \approx I_{E1}
   \]
   \[
   I_O = I_{C2}
   \]

3. Choose \( R_{ref} \) for the desired current:
   \[
   R_{ref} = \frac{V_{CC} - 0.7}{I_{REF}} \approx \frac{V_{CC} - 0.7}{I_{C1}}
   \]

4. If \( Q1 = Q2 \) matched and \( V_{CE2} = V_{CE1} \)
   \[
   \text{then } I_{C2} = I_{C1}
   \]
   \[
   \Rightarrow I_O \approx I_{ref}
   \]
**Constant Emitter Current**

Now: \( V_{BE1} = V_{BE2} \)

If \( Q_1 \) and \( Q_2 \) have the same saturation current: \( I_{S1} = I_{S2} \)

And the transistors are at the same temperature: \( T_1 = T_2 \)

The two collector currents – set primarily by \( R_{ref} \) – are equal, as long as \( Q_2 \) is not saturated.

\[
I_O = I_{C2} = I_{ref} \approx \frac{V_{CC} - 0.7}{R_{ref}}
\]

Since \( V_{CE1} \neq V_{CE2} \), the Early Effect needs to be included in simulations.
Emitter Current Bias Quick Review

What is the circuit in the green box?

What is the relation between $R_{ref}$ and $I_{REF}$?

What is the approximate relation between $I_{REF}$ and $I_E$?

Does $V_{BE1} = V_{BE2}$?

Does the Early Voltage affect the relation between $I_{REF}$ and $I_E$? How?

What is the output resistance of Q2?
Emitter Current Bias Quick Review

What is the circuit in the green box?

Current mirror to realize a fixed current source.

What is the relation between $R_{ref}$ and $I_{REF}$?

What is the approximate relation between $I_{REF}$ and $I_E$?

Does $V_{BE1} = V_{BE2}$?

Does the Early Voltage effect the relation between $I_{REF}$ and $I_E$? How?

What is the output resistance of Q2?
Emitter Current Bias Quick Review

What is the circuit in the green box?

Current mirror to realize a fixed current source.

What is the relation between $R_{\text{ref}}$ and $I_{\text{REF}}$?

$$I_{\text{REF}} = \frac{V_{\text{CC}} - V_{\text{BE1}}}{R_{\text{ref}}}$$

What is the approximate relation between $I_{\text{REF}}$ and $I_E$?

Does $V_{\text{BE1}} = V_{\text{BE2}}$?

Does the Early Voltage effect the relation between $I_{\text{REF}}$ and $I_E$? How?

What is the output resistance of Q2?
Emitter Current Bias Quick Review

What is the circuit in the green box?

Current mirror to realize a fixed current source.

What is the relation between $R_{\text{ref}}$ and $I_{\text{REF}}$?

$$I_{\text{REF}} = \frac{V_{CC} - V_{BE1}}{R_{\text{ref}}}$$

What is the approximate relation between $I_{\text{REF}}$ and $I_E$?

$I_E \approx I_{\text{REF}}$

Does $V_{BE1} = V_{BE2}$?

Does the Early Voltage effect the relation between $I_{\text{REF}}$ and $I_E$? How?

What is the output resistance of Q2?
Emitter Current Bias Quick Review

What is the circuit in the green box?

Current mirror to realize a fixed current source.

What is the relation between $R_{\text{ref}}$ and $I_{\text{REF}}$?

$$I_{\text{REF}} = \frac{V_{CC} - V_{BE1}}{R_{\text{ref}}}$$

What is the approximate relation between $I_{\text{REF}}$ and $I_E$?

$$I_E \approx I_{\text{REF}}$$

Does $V_{BE1} = V_{BE2}$? Yes

Does the Early Voltage effect the relation between $I_{\text{REF}}$ and $I_E$? How?

Yes, $V_{CE2} \neq V_{CE1}$

What is the output resistance of Q2?
Emitter Current Bias Quick Review

What is the circuit in the green box?

Current mirror to realize a fixed current source.

What is the relation between \( R_{ref} \) and \( I_{REF} \)?

\[
I_{REF} = \frac{V_{CC} - V_{BE1}}{R_{ref}}
\]

What is the approximate relation between \( I_{REF} \) and \( I_E \)?

\[
I_E \approx I_{REF}
\]

Does \( V_{BE1} = V_{BE2} \)? Yes

Does the Early Voltage effect the relation between \( I_{REF} \) and \( I_E \)? How? Yes, \( V_{CE2} \neq V_{CE1} \)

What is the output resistance of Q2?

\[
r_o = \frac{V_A'}{I_C'} \quad I_C' = I_S e^{v_{BE}/V_T}
\]
Constant Emitter Current – Early Voltage

Assume Q1 = Q2

For Q2:

\[ I_O = I_{C2} = I_S e^{V_{BE1} / V_T} \left( 1 + \frac{V_{CE2}}{V_A} \right) \]  \hspace{1cm} (1)

Since \( I_B \) is not effected by \( V_A \), i.e.

\[ I_{B2} = \frac{I_S}{\beta} e^{V_{BE2} / V_T} = \frac{I_{C2}}{\beta_F} \]

where \( \beta_F = \beta \left( 1 + \frac{V_{CE2}}{V_A} \right) \)

For Q1:

\[ I_{B1} = I_{B2} \]

\[ I_{REF} = I_{C1} + I_{B1} + I_{B2} = I_{C1} + 2 I_B \]

\[ I_{REF} = I_S e^{V_{BE1} / V_T} \left( 1 + \frac{V_{CE1}}{V_A} \right) + 2 I_S e^{V_{BE} / V_T} \]

Solving for \( I_S e^{V_{BE1} / V_T} \)

\[ I_S e^{V_{BE1} / V_T} = \frac{I_{REF}}{1 + \frac{V_{BE}}{V_A} + 2 \frac{V_{BE}}{V_T} \beta} \]  \hspace{1cm} (2)

Sub (2) into (1)

\[ I_O = I_{C2} = \frac{I_{REF}}{1 + \frac{V_{CE1}}{V_A} + 2 \frac{V_{BE}}{V_T} \beta} \]

Ideally

\[ = 1 \]
Constant Emitter Current – Early Voltage Cont.

\[ I_O = I_{C2} = I_{REF} \frac{1 + \frac{V_{CE2}}{V_A}}{1 + \frac{V_{BE}}{V_A} + \frac{2}{\beta}} \]

\[ \frac{I_O}{I_{REF}} = \frac{1 + \frac{V_{CE2}}{V_A}}{1 + \frac{V_{BE}}{V_A} + \frac{2}{\beta}} \]

Let \( V_A = \infty \Rightarrow \text{Early effect is negligible} \)

If also \( \beta = \infty \Rightarrow I_O = I_{REF} \)

Let \( V_A = \text{finite} \) and \( V_A = 50 \, \text{V}, \) \( V_{BE} = 0.7 \, \text{V}, \) \( \beta = 100 \)

\[ \frac{I_O}{I_{REF}} = f(V_{CE2}) = \frac{1 + 0.02 V_{CE2}}{1.034} = 0.97 \left(1 + 0.02 V_{CE2}\right) \]
We thus can use a current mirror to provide stable control of transistor collector current. \( R_{\text{ref}} \) sets the emitter and collector currents and the collector-ground voltage for \( Q_{\text{amp}} \).

\( v_{\text{in}} \) is the ac input voltage source.

\( R_B \) can be any “reasonable” value – this is not voltage biasing!
Summary

- Two practical methods for achieving stable bias for a BJT are:
  - Use a dc voltage source in the base with a feedback resistance in the emitter circuit.
  - Place a dc current source directly in the emitter circuit.
Emitter-Feedback Bias Design

1. Use single supply for base bias and collector sources.

2. Use the $I_C/10$ rule for the current $I_1$ through the base bias network ($R_1$ and $R_2$).

3-1. Try less negative feedback using a smaller emitter resistor $R_E$ “saving” more of the $V_{CC}$ supply voltage for $V_{CE}$ & the $R_C$ voltage drop $V_{RC}$.

or

3-2. Use the “$1/3, 1/3, 1/3$ Rule”.

Kenneth R. Laker, update 16Sep13
Let's Try “Emitter-Feedback 3-1” Bias Design

Complete the bias design given the following design values:

\[ V_{CC} = 12 \text{ V} \quad I_C = 1 \text{ mA} \quad V_C = 6 \text{ V} \]

\[ \beta = 100 \Rightarrow \alpha = 0.99 \quad \& \quad V_{BE} = 0.7 \text{ V} \]

It follows:

\[ R_C = \frac{V_{Re}}{I_C} = \frac{V_{CC} - V_C}{I_C} = 6 \text{ k}\Omega \quad V_{Re} = 6 \text{ V} \]

\[ I_1 = \frac{I_C}{10} = 0.1 \text{ mA} \Rightarrow R_1 + R_2 = \frac{V_{CC}}{I_1} = \frac{12}{10^{-4}} = 120 \text{ k}\Omega \]
Let's choose a small feedback voltage, say $V_{Re} = 1\, V$ (i.e. $V_{CE} = 5\, V$). Ignoring the base current:

$$R_E = \frac{V_{Re}}{I_E} = \frac{1\, V}{I_C/\alpha} = 990\, \Omega$$

Then the voltage across $R_2$ is $V_B = 1.7\, V$

$$R_2 = \frac{1.7\, V}{10^{-4}\, A} = 17\, k\, \Omega$$

$$R_1 = 120\, k\, \Omega - 17\, k = 103\, k\, \Omega$$

Recall: $R_B \leq \frac{1}{10} (\beta + 1) R_E$

$$R_B = R_1 \| R_2 \approx 14.5\, k\, \Omega > \frac{1}{10} (\beta + 1) R_E \approx 9.9\, k\, \Omega$$
3-2 ("1/3, 1/3, 1/3 Rule") Bias Design

Let's choose \( V_{RC} = V_B = \frac{V_{CC}}{3} = 4 \) V

\[
R_C = \frac{V_{RC}}{I_C} = \frac{4 \text{ V}}{10^{-3} \text{ A}} = 4 \text{ k}\Omega
\]

\[
R_E = \frac{4 \text{ V}}{I_C/\alpha} = 3.96 \text{ k}\Omega
\]

The voltage across \( R_2 \) is \( V_B = V_{RE} + V_{BE} = 4.7 \) V

\[
R_2 = \frac{4.7 \text{ V}}{10^{-4} \text{ A}} = 47 \text{ k}\Omega
\]

\[
R_1 = 120k - 47k = 73 \text{ k}\Omega
\]

Recall: \( R_B \leq \frac{1}{10} (\beta + 1) R_E \)

\[
R_B = R_1 \parallel R_2 \approx 28.6 \text{ k}\Omega < \frac{1}{10} (\beta + 1) R_E \approx 33 \text{ k}\Omega
\]
**RECALL: Bias Stability Condition Argument**

\[ V_B = I_B R_B + V_{BE} + (\beta + 1) R_E I_B \]

\[ I_B = \frac{V_B - V_{BE}}{R_B + (\beta + 1) R_E} \]

\[ I_C = \beta I_B = \frac{\beta}{R_B + (\beta + 1) R_E} (V_B - V_{BE}) \]

if \( R_B \ll (\beta + 1) R_E \)

\[ I_C = \beta I_B \approx \frac{\beta}{\beta + 1} \frac{(V_B - V_{BE})}{R_E} = \alpha \frac{(V_B - V_{BE})}{R_E} \]
"Emitter-Feedback 3-1" $\beta$ Sensitivity

\[ I_C = \beta I_B = \frac{\beta}{R_B + (\beta + 1) R_E} (V_B - V_{BE}) \]

- $V_{CC} = 12V$
- $V_B = 1.7 V$
- $V_{BE} = 0.7 V$
- $I_C = 1 mA$
- $\beta = 100$
- $R_C = 6k\Omega$
- $R_E = 1 k\Omega$
- $R_B = 14.5 k\Omega$

\[ \beta = 100; \quad I_C = 0.873 mA \]

\[ \beta = 200; \quad I_C = 0.932 mA \]

\[ \beta = \infty; \quad I_C = 1 mA \]

\[ \beta = 100 \text{ & } R_B = 0 \Omega; \quad I_C = 0.99 mA \]
“Emitter-Feedback 3-1” Bias Scilab Simulation

//3-1 Bias Scheme with Re=1 K
Beta=100;
VsubT=0.025;
VB=1.7;
Rb=14.5;
Re=1;
BetaPlusRe=101;
vBE=0.0:0.01:1;
iCline=Beta*(VB-vBE)/(Rb+BetaPlusRe);//mA.
plot(vBE,iCline);
iC=0.01:0.01:2;//mA!
IsubS =1E-16;//mA.
for k= 1:1:8
    IsubS=10*IsubS;
vBE2=VsubT*log(iC/IsubS);
    plot(vBE2,iC); //Current in mA.
end

\[ I_c = \frac{\beta}{R_B + (\beta + 1)R_E} (V_B - V_{BE}) \]
Scilab Plot (Zoomed)

\[ I_S = 10^{-11} \]

\[ I_S = 10^{-18} \]

\[ \Delta I_C \approx 0.4 \text{mA} \]
“Emitter-Feedback 3-2” $\beta$ Sensitivity

\[ I_C = \frac{\beta}{R_B + (\beta + 1)R_E} (V_B - V_{BE}) \]

- $V_{CC} = 12V$
- $V_B = 1.7V$
- $V_{BE} = 0.7V$
- $I_C = 1 mA$
- $\beta = 100$
- $R_C = 4k\Omega$
- $R_E = 3.96k\Omega$
- $R_B = 28.6k\Omega$

Emitter-Feedback 3-1

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$I_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.873 mA</td>
</tr>
<tr>
<td>200</td>
<td>0.932 mA</td>
</tr>
<tr>
<td>$\infty$</td>
<td>1 mA</td>
</tr>
<tr>
<td>100 &amp; $R_B = 0\Omega$</td>
<td>0.99 mA</td>
</tr>
</tbody>
</table>

Kenneth R. Laker, update 16Sep13
Compare to $I_C$ vs $I_S$ Results Plot with 3-2 Emitter Feedback

$I_S = 10^{-11}$ Collector Current Variation With $I_S$

$I_S = 10^{-18}$

$\Delta I_C \approx 0.2 \text{ mA}$
Conclusion

- “1/3, 1/3, 1/3 Rule” Provides a Good Compromise Base Voltage Bias Scheme for circuits implemented with discrete BJTs.

- Emitter current bias scheme using a current mirror is an effective bias scheme for BJT circuits implemented as ICs.