BJT Review

\( I_C = \beta I_B \)

Current flows between E & C
(direction depends on pnp or npn)

EB is a diode, must be forward biased for Active or Saturation

\( I_C = \alpha I_E \)

(pnp models)

Biasing for Amplifiers

Fixed

\[ V_{BB} \]

\[ R_B \]

\[ R_C \]

\[ \text{Fixed} \]

\[ V_{cc} \]

\[ R_c \]

\[ R_1 \]

\[ R_2 \]
Designing The Bias Circuit

1. Choose "quiescent" current $I_{CQ} = I_{EQ}$ (horizontal line on $I_C$ vs $V_{EB}$)

2. Pick $V_{CC}$

3. Pick $V_E = \frac{1}{10} V_{CC}$ $\Rightarrow$ $R_E = \frac{1}{10} \frac{V_{CC}}{I_{CQ}}$

   Thermal stability, good gain

4. Determine $V_B = V_E + V_{BE} = V_E + 0.6$

5. Pick $I_{I2} = \frac{1}{10} I_{CQ}$

   (one tenth rule of thumb)

6. Calculate $R_2 = \frac{V_B}{I_{I2}}$

7. Calculate $R_1 = \frac{V_{CC} - V_B}{I_{I2}}$

8. Pick $V_C = \frac{V_{CC}}{2}$

9. Calculate $R_C = \frac{V_{CC}}{I_C}$
To increase gain at high frequencies add $C_E$

$$\frac{1}{\omega C_E} \ll R_E$$

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**Transistor Circuit Configurations**

One of the three leads is connected to a power supply (stiffly)

1. **Common Emitter**
   - $V_{cc}$
   - $R_e$
   - $V_{out}$
   - $V_{in}$

2. **Common Base**
   - $V_{cc}$
   - $R_e$
   - $V_{out}$
   - $V_{in}$

3. **Common Collector**
   - $V_{ee}$
   - $R_e$
   - $V_{out}$
   - $V_{in}$

**Amplifier**  
**Rarely Used**  
**Current Amp?**  
**Emitter**  
**Collector**
Common Emitter Amplifier

Adding little variations to the large biasing (quiescent) voltages & currents

Use big subscripts for the biasing values
Use little subscripts for the variations
We will tend to forget about the biasing currents altogether!

Small-signal models

First let's find input resistance

\[ R = \frac{\partial V}{\partial I} \] : How much the voltage changes for a small current change

\[ r_{in} = \frac{V_b}{I_b} = \frac{\partial V}{\partial I} \]

Need full current

\[ I_E = I_C = I_S (e^{\frac{V_{BE}}{V_T}} - 1) \approx e^{\frac{V_{BE}}{V_T}} \]

\[ \frac{dI_C}{dV_B} = \frac{I_C}{V_T} = \frac{1}{r_{in}} \]

\[ dI_B = \frac{1}{\beta} dI_C \]

\[ \frac{dI_B}{dV_B} = \frac{1}{r_{in}} = \frac{I_C}{\beta V_T} \]

\[ r_E = \frac{dI_E}{dV_E} = \frac{V_T}{I_C} \]

\[ r_{in} = \frac{\beta V_T}{I_C} \]

\[ \beta = \frac{I_C}{I_B} \]

\[ r_{in} = \frac{r_{pi}}{\beta} \]
Can also state the problem with a "transconductance"

\[ i_b = \frac{V_{be}}{r_{in}} \quad i_c = \beta i_b = \frac{B V_{be}}{r_m} = g_m V_{be} \]

\[ g_m = \frac{I_c}{V_T} \]
Assume $R_s \ll P_f \Rightarrow V_{in} \approx V_b$ \hfill (6)

$$i_b = \frac{V_{in}}{r_{in}} = \frac{V_{in} I_c}{\beta V_T}$$

$$i_c = \beta i_b = \frac{V_{in} I_c}{V_T}$$

$$V_c = V_{out} = \beta i_c R_0 = -V_{in} \frac{I_c R_0}{V_T} = -\frac{R_0}{r_{in}}$$

$$G = \frac{V_{out}}{V_{in}} = -\frac{I_c R_0}{V_T} = -\frac{R_0}{r_{in}} \quad (= A)$$

$R_{in} \rightarrow R_{in//r_{in}}$

**Common Collector**

$V_{in} \rightarrow V_{in}$

$V_{out} \rightarrow \beta i_b R_E$

$$V_{out} = (i_b + i_c) R_E = i_b (1+\beta) R_E$$

$$V_{in} - V_{out} = r_{in} i_b$$

$$V_{in} = (r_{in} + (1+\beta) R_E) i_b$$
\[ G = \frac{V_{out}}{V_{in}} = \frac{(1 + \beta)R_E}{V_{in} + (1 + \beta)R_E} = \frac{1}{1 + \frac{V_{in}}{(1 + \beta)R_E}} = \frac{1}{1 + \frac{V_{in}}{I_E R_E (1 + \beta)}} \]

Consider \( p = 100, I_c = 100\, \text{mA}, \ R_E = 4.7\, \text{kΩ} \)

\[ \frac{V_T}{R_E I_c} = \frac{25}{4700} = \frac{1}{2 \times 10^2} \]

\[ G = \frac{1}{1.605} \approx 0.625 \]

Change \( R_E \) to \( 50\, \text{kΩ} \) \( (R_h = 50\, \text{kΩ}) \)

\[ \frac{V_T}{R_E I_c} = \frac{25}{50} = \frac{1}{2} \]

\[ G = \frac{1}{1.5} = \frac{2}{3} \]

With light loads emitter of emitter follower is same as base.

\[ V_{out} = V_{in} - 0.6\, \text{V} \] in DC.

**Full Small-Signal Model: \( h \)-parameters**

![Diagram of small-signal model](image)

4 parameters: 2 independent, 2 dependent

\[ i_m, V_{out}, i_{out}, V_{in} \]

\[ \Delta I_{out} = i_{out} = \left( \frac{\partial I_{out}}{\partial I_m} \right)_{V_{out} constant} i_m + \left( \frac{\partial I_{out}}{\partial V_{out}} \right)_{I_m constant} V_{out} \]

\[ V_{in} = \left( \frac{\partial V_{in}}{\partial I_m} \right)_{V_{out} constant} i_m + \left( \frac{\partial V_{in}}{\partial V_{out}} \right)_{I_m constant} V_{out} \]
\[ i_{out} = h_{re} \cdot i_{in} + h_{oe} \cdot v_{out} \]
\[ v_{in} = h_{ie} \cdot i_{in} + h_{re} \cdot v_{out} \]

For 2N4401 with \( I_c = 1 \text{ mA} \) \( V_{EE} = 10 \text{ V} \) \( f = 1 \text{ kHz} \)

\[ \beta = h_{re} = 40 - 500 \text{ forward gain} \]
\[ h_{oe} = 1 - 30 \mu \Omega \text{ output admittance} \]
\[ h_{ie} = 1 - 15 \text{ k}\Omega \text{ input resistance} \]
\[ h_{re} = 0.1 - 8 \times 10^{-4} \text{ reverse} \]

Common Emitter Spec. Sheets!
Gain \ (h_{re} = 0, \ h_{oe} = 0) \quad
\begin{align*}
V_{out} &= -i_c R_c \\
&= -i_b h_{re} R_c \\
&= -\left(\frac{V_{in}}{h_{ie}}\right) h_{oe} R_c
\end{align*}
\begin{align*}
G &= \frac{V_{out}}{V_{in}} = -\frac{h_{oe}}{h_{ie}} R_c
\end{align*}

Input impedance: \ R_B // h_{ie} \\
Output impedance: \ R_{out} = \frac{dV_{out}}{di_{out}} \\
\begin{align*}
&= R_c \ \frac{\Delta i}{\Delta i_{out}} = R_c
\end{align*}
Complementary Circuits
Putting together transistors.

Darlington Configuration
Can cascade transistors to increase input impedance & gain

Double BE drop

Single BE drop

$\beta = \beta_1 \beta_2$, want $\beta_1$ large, at small $I_C$
The Current Mirror

Diode Connected Configuration

\[ V_{CB} = 0 \]

If \( V_{BE} > 0.6 \), current flows

It's a diode!

(but most of current flows through \( C \) and \( B \))

Now take two identical transistors
(on same piece of silicon)

One \( Q \) is diode-connected

Control \( I \) via \( V_C \) and \( R \)

\[ I_i = \frac{V_C}{R} = I_B + i_C = \frac{V_C}{R} \]

Since \( Q \)'s identical, \( i_B = \frac{1}{2} I_B \)
(two equivalent paths to ground)

\[ I_0 = \beta i_B \quad I_i = 2i_B + i_C = i_B(2 + \beta) \]

\[ i_B = \frac{I_i}{2 + \beta} \]

\[ = \frac{\beta}{2 + \beta} I_i = I_i \frac{1}{1 + \beta} \]
Better Current Mirror
(Put less current into bases!)

\[ I_{in} \leq R \]

\[ Q_1 \rightarrow Q_2 \rightarrow Q_3 \]

Two \( \beta \) factors
\[ R = I_B \]

Need \( \beta \) of \( I_{in} \) at \( Q_1 \)

Need \( \frac{1}{\beta} \) of \( I_B \) at \( Q_3 \)

\[ I_0 = \frac{1}{1 + \beta^2} \cdot I_{in} \]