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

Consider \( \beta = 100, I_C = 500 \mu A, R_E = 4.7 k\Omega \)

\[ \frac{V_T}{R_E I_C} = \frac{25}{0.4700} = \frac{1}{2} \times 10^{-2} \]

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

Change \( R_E \) to 50 Ω \( (R_L = 50 \Omega) \)

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

\[ G = \frac{1}{1.5} = 0.667 \]

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

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

\[ \text{Full Small-Signal Model: } h \text{-parameters} \]

\[ \Delta I_{out} = I_{out} = \frac{\partial I_{out}}{\partial I_{in}} \bigg|_{V_{out} \text{ const}} I_{in} + \frac{\partial I_{out}}{\partial V_{out}} \bigg|_{I_{out} \text{ const}} V_{out} \]

\[ V_{in} = \frac{\partial V_{in}}{\partial I_{in}} \bigg|_{V_{out} \text{ const}} I_{in} + \frac{\partial V_{in}}{\partial V_{out}} \bigg|_{I_{out} \text{ const}} V_{out} \]
\[ i_{out} = h_{re} \cdot i_{in} + h_{oe} \cdot v_{out} \]

\[ v_{in} = h_{ie} \cdot i_{in} + h_{re} \cdot v_{out} \]

For AN4401

\[ V = 1 \, \text{kHz} \]

\[ P_{re} = h_{re} = 40 - 500 \quad \text{forward gain emitter} \]

\[ h_{oe} = 1 - 30 \, \text{pF} \quad \text{output admittance} \]

\[ h_{ie} = 1 - 15 \, \text{k}\Omega \quad \text{input resistance} \]

\[ h_{re} = 0.1 - 8 \times 10^{-4} \quad \text{reverse} \]

Common Emitter Fig. Spec. Sheets!
Gain (\( h_{re} = 0, \ h_{ce} = 0 \))

\[
V_{out} = -ic \cdot R_c = -q_b \cdot h_{re} \cdot R_c = -(\frac{V_{in}}{h_{ie}}) \cdot h_{re} \cdot R_c
\]

\[
G = \frac{V_{out}}{V_{in}} = -\frac{h_{re}}{h_{ie}} \cdot R_c
\]

Input impedance: \( R_B \parallel h_{ie} \)

Output impedance: \( R_{out} = \frac{\Delta V_{out}}{\Delta I_{out}} \)

\[
= R_c \frac{\Delta c}{\Delta i_{out}} = R_c
\]
Darlinton 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 \( V_{BE} \geq 0.6 \), current flows
It's a diode!
(but most of current flows thru \( C \) and \( B \))

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

One is diode-connected

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

\[ I_i = \frac{V_c}{R} = I_B + i_c = I_B + \beta I_B \]

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

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

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

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

\[ I_0 = \frac{1}{1 + \frac{3}{\beta}} I_{in} \]

Two \( \beta \) factors

\[ R = I_B \]

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

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

The Push-Pull Emitter Follower

Single Emitter Follower has to be biased

Can remove biasing by using complementary transistors
Use Model 2 (simple, not simplest) model to analyze

When $V_s > 0.7 \, V$ : $i_{E_1} > 0$, $Q_1$ on, $Q_2$ off

$V_s < -0.7 \, V$: $i_{E_2} > 0$, $Q_2$ on, $Q_1$ off

$-0.7 < V_s < 0.7 \, V$ Both off, $V_2 = 0$

This is cross-over distortion
Reducing Crossover Distortion

Method 1: Add diode drops

Method 2: Feedback

OpAmp does what it needs to
to keep \( V_2 = V_s \)
Differential Pair

Emitter coupled amplifier … pair
Current source biasing (current mirror!)

Use identical transistors
(e.g., on same chip)

Consider small signal model
(disregard \( h_{fe} \) & \( h_{re} \))

Use KVL:

\[ V_1 - \alpha_1 V_1 + \alpha_2 V_2 - V_2 = 0 \]

\[ i_{e1} + i_{e2} = 0 \]

\[ V_1 = V_2 = \frac{V_1}{I_B} \hspace{1cm} (\text{check, not } I_e?) \]

\[ I_B = \frac{I_o}{\alpha \beta} \]

\[ V_1 - V_2 = \frac{1}{\alpha_f} (i_{b2} - i_{b1}) \]

\[ i_{a1} = -i_{e2} \Rightarrow i_{d1} = -i_{b2} \]

\[ = \frac{2\beta V}{I_o} \cdot i_{b2} \]
Differential Gain

\[ V_{62} = -\beta \frac{v_2}{R_c} = -\beta \frac{v_2}{R_c} \]

\[ = \frac{(V_i - V_2) I_o R_c}{4 V_T} \]

\[ C = \frac{V_{62}}{V_i - V_2} = \frac{I_o R_c}{4 V_T} = \frac{R_c}{2 R_F} \]

Common Mode Gain

\[ V_{62} \text{ depends on } v_1 + v_2 \text{ in some way} \]

None for perfect current source

Common-Mode Rejection Ratio

\[ \frac{C_{\text{diff}}}{C_{\text{cm}}} \]

Miller Effect

What happens with BJT's at high frequencies.

\[ \begin{array}{c}
\text{E} \\
\text{B} \\
\text{C}
\end{array} \]

\[ C_{\text{eb}} \quad C_{\text{bc}} \]

for 2N4401

\[ C_{\text{eb}} = 6.5 \text{pF} \]

\[ C_{\text{bc}} = 30 \text{pF} \]

Add capacitors to simplified small signal model

\[ C_{\text{eb}} \quad C_{\text{bc}} \]

\[ \begin{array}{c}
V_i \\
\text{b} \\
\text{c}
\end{array} \]

\[ \frac{i_c}{C_{\text{eb}}} \]

\[ V_o \]

\[ C_{\text{eb}} \quad R_c \]

\[ C_{\text{bc}} \quad R_c \]

\[ C_{\text{bc}} \text{ is extra load on } V_i, \text{ fold into source's output} \]
Gain calculation at high frequency

\[ i_b = \frac{V_{in}}{r_{in}} \]

\[ i_c = \frac{V_{in} - V_o}{1/sC_{eb}} \]

\[ V_o = (\beta i_o + i_c)R_c \]

\[ = (\beta \frac{V_{in}}{r_{in}} - C_{eb}s(V_{in} - V_o))R_c \]

\[ \frac{V_o}{V_{in}} = - \frac{\beta R_c/r_{in} - R_CC_{eb}s}{1 + R_CC_{eb}s} = -A \]

\[ \frac{1}{1 + R_CC_{eb}s} \] is a low pass filter

Input impedance at high freq.

\[ Z_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{i_b + i_c} \]

\[ = \frac{V_{in}}{V_{in}/r_{in} + C_s(V_{in} - V_o)} \]

\[ = \frac{1}{1/r_{in} + C_s(1 + A)} \]

\[ Z_{in} = r_{in} // (1 + A)C_{eb} \]

Miller Effect

(Ceb also parallel, but Ceb dominates)
Another Low Pass Filter

For $R_s \ll 2a$, this filter (input impedance) dominates.

To avoid Miller effect:

$V_c$ changes less than $V_B$

Cascaded Q's & BC pairs do this.