Common Base Amplifier

Conventional biasing components

Small signal model

Thermal equivalent of the circuit in the emitter

\[ B_{se} = R_i R_s \]

If \( R_s \) is small, \( B_{se} \approx R_s \)

\[ V_{ce} = \frac{R_E V_i}{R_s + R_E} \]

Applying the same methodology as in the case of CE amplifier, one obtains

1) \[ A_v = \frac{g_m R_a \beta \tau_t}{R_s + \tau_t + g_m R_{se} \tau_t} = \frac{\beta R_c}{\tau_t + R_s (1 + \beta)} \]

2) \[ A_i = \frac{g_m \tau_t}{1 + g_m \tau_t} \approx \frac{1}{1 + \beta^2} \]

3) \[ R_i = \frac{\tau_t}{1 + \beta} \approx \frac{1}{g_m} \]
4) \( R_o = \frac{V_o}{I_o} \approx \frac{V_o}{(1 + \beta) I_o} \cdot \frac{1}{R_e + (1 + \beta) R} \)

Compared to CE amplifier, CB has the following properties:

1) Similar voltage gain (somewhat smaller) - non-inverting
2) Same current gain \( \approx 1 \)
3) Same input impedance
4) Similar output impedance

**Common Collector - Emitter Follower**

![Diagrams of electronic circuits]

Configuration including biasing components

Small signal model

Applying the same methodology as in the case of CE, one obtains:

\[
A_v = \frac{V_o}{V_i} = \frac{((1 + \beta) R_e) \cdot R}{R_o + (1 + \beta) R_e} + R_e
\]

\[
R_o = \frac{V_o}{I_o} \cdot \frac{1}{R_e + (1 + \beta) R} \approx \frac{V_o}{(1 + \beta) I_o}
\]
1) \[ A_i = \frac{I_i}{I_i} = \frac{(1 + g_m R_o) R_o}{R_o + P_L} \approx 1 + \beta \]

2) \[ R_i = R_o + (1 + \beta) R \| R_e \]

3) \[ R_o = \frac{R_o (R_o + R_s)}{R_o + R_s + R (1 + \beta)} \]

Compared to CE, CC has the following properties:

1) Voltage gain is approximately equal to one.

2) Approximately the same current gain.

3) Very high input impedance (excellent buffering circuit).

4) Very low output impedance (excellent output voltage source).

Common Emitter with Emitter degeneration

\[ R_{E1} + R_{E2} = R_E \text{ - used for temperature stabilization} \]

\[ R_{E1} \text{ - present in the small signal path of the circuit} \]

Benefits:

1) Temperature stabilization, feedback from BE

2) High input impedance

x Used quite often in discrete RF circuits.
If one assumes $r_o \to \infty$, the circuit simplifies.

$$\begin{align*}
V_c & = V_i - \frac{R_c}{R_b} V_i \\
V_c & = \frac{R_c}{R_b} V_i
\end{align*}$$

1) $A_v = \frac{V_o}{V_i} = -\frac{R_c}{R_b} \frac{R_b}{R_{S+R_b} + \frac{R_b}{1+\beta R_b} R_E}$

2) $A_i = \beta$

3) $R_i = R_b + (1+\beta) R_E$

4) $R_o = R_{S+R_b}$

**Differential amplifier**

Very popular in integrated circuits - biasing does not require additional resistors - the input is directly coupled to the honesins (no large capacitors for coupling required) - multiple stages may be coupled directly

Analysis of the gain: (Trans assumed infinite)

$$V^+ - V_{BE_1} + V_{BE_2} - V^- = 0$$
Or, \( V_{B2} - V_{B1} = V^+ - V^- = U_d \quad U_d \ - \) differential voltage

On the other hand, \( V_{BE1} = V_t \ln \left( \frac{I_{C1}}{I_{SS1}} \right) \quad I_e = \frac{I_C}{\alpha} \quad \alpha = \frac{1}{1 + \beta} \)

\( V_{BE2} = V_t \ln \left( \frac{I_{C2}}{I_{SS2}} \right) \quad I_{E2} = \frac{1}{\alpha} \cdot I_{C2} \)

\( I_{E1} + I_{E2} = I_{T} \)

Therefore

\( V_t \ln \left( \frac{I_{C2}}{I_{C1}} \right) = V_t \ln \left( \frac{I_{C1}}{I_{SS1}} \right) = U_d \)

\( I_{C1} + I_{C2} = \alpha \cdot I_{T} \)

If the transistors are manufactured "in pair", i.e., they have ideally the same characteristics, one obtains

\( V_t \ln \left( \frac{I_{C2}}{I_{C1}} \right) = U_d \)

\( I_{C1} + I_{C2} = \alpha \cdot I_{T} \)

Two equations with two unknowns, but can be solved as:

\( I_{C1} = \frac{\alpha \cdot I_{T}}{1 + \exp \left( -\frac{U_d}{V_t} \right)} \)

\( I_{C2} = \frac{\alpha \cdot I_{T}}{1 + \exp \left( \frac{U_d}{V_t} \right)} \)

\( V_t = (V_{CC} - R_C I_{C1}) - (V_{CC} - R_C I_{C2}) = \)

\( = R_C (I_{C2} - I_{C1}) = R_C \left[ \frac{\alpha I_{T} \frac{1}{1 + \exp (\frac{U_d}{V_t})}}{1 + \exp (\frac{-U_d}{V_t})} \right] \)
\[ v_0 = \alpha \text{Re} \left[ I_n \frac{\exp(-vd/2\nu_T)}{\exp(-vd/2\nu_T) + \exp(vd/2\nu_T)} \right] \]

\[ = -\alpha \text{Re} \tan \left( \frac{vd}{2\nu_T} \right) \]

\[ \alpha \text{Re} \tan(\frac{vd}{2\nu_T}) \]

\[ v_0 \]

\[ -3 \]

\[ v_{d/2\nu_T} \]

- Nonlinear relationship between input and output.
- Gain approximately linear.

Small signal characteristics of a balanced BJT differential amplifier.

\[ v_1 = v_d/2 \quad e_c = v_1 + v_2 \]

\[ v_2 = v_d/2 \quad v_d = v_1 - v_2 \]

Two parameters are of paramount importance:

1) Differential gain \( A_d \) = \( \frac{v_{o}}{e_d} \)

2) Common mode gain \( A_c \) = \( \frac{v_{o}}{e_{ic}} \)

Fundamental measure of differential amplifier is the COMMON MODE REJECTION RATE.
which is defined as

\[ CHRE = \frac{Ad}{Ac} \]

If \( CHRE \) is used, the actual output of the amplifier may be expressed as

\[ V_o = Ad \cdot e_d + Ac \cdot e_c = Ad \left( e_d + \frac{1}{CHRE} e_c \right) \]

In good differential amplifiers, \( CHRE \) is large and

\[ V_o \approx Ad \cdot e_d \Rightarrow \text{does not depend on common mode between the inputs} \]

**Small signal model for BJT differential amplifier**

![Diagram of BJT differential amplifier]

\[ V_{E-} = V_{E-} - \frac{V_{id/2}}{R-ST} + \frac{V_{E-}}{R-ST} - g_m V_{be1} - g_m V_{be2} = 0 \quad (x \times) \]

\[ V_{be1} = \frac{V_{id}}{2} - V_{E-} \quad (x) \]

\[ V_{be2} = -\frac{V_{id}}{2} - V_{E-} \quad (x) \]

Substituting \((x) \Rightarrow (x \times)\), one obtains

\[ V_{E-} \left( \frac{1}{R_{T\text{ail}}} + \frac{1}{2R-ST} \right) - \frac{V_{id}}{2R-ST} + \frac{V_{id}}{2R-ST} - g_m \left( \frac{V_{id}}{2} - V_{E-} \right) - g_m \left( -\frac{V_{id}}{2} - V_{E-} \right) = 0 \]
or \[ V_E = \left( \frac{1}{R_{MC}} + \frac{2}{R_T} + 2g_m \right) = 0 \] \[ \Rightarrow \] \[ V_E = 0 \]

\( V_E \) ads as a ground for small signals. (This is a consequence of perfect balance between the two sides of the amplifier.)

As a result, the circuit may be split into two parts.

\[ \frac{V_{od}}{2} = -g_m \cdot R_c \cdot \frac{V_{id}}{2} \]

and

\[ V_{od} = -g_m \cdot R_c \cdot V_{id} - (+g_m \cdot R_c \cdot \frac{V_{id}}{2}) = -g_m \cdot R_c \cdot V_{id} \]

or \[ A_d = -g_m \cdot R_c \]

Therefore, the differential gain is approximately the same as CE configuration.

Homework: 2.2, 2.6, 2.18, 2.21
Common mode gain

The circuit is symmetric, \( \beta = 0 \)

Based on the half of the circuit

\[
\begin{align*}
V_{be} &= g_{m} I_C \\
\beta &= \frac{V_{be}}{V_{ic}} \\
\alpha &= g_{m} R_C \\
A_{cm} &= \frac{g_{m} R_C}{1 + g_{m} (2 R_{ic} \beta)}
\end{align*}
\]

Therefore, CHMR = \( 1 + g_{m} (2 R_{ic} \beta) \) - depends on the tail resistor of the current source.