Common Base BJT Amplifier
Common Collector BJT Amplifier

- Common Collector (Emitter Follower) Configuration
- Common Base Configuration
- Small Signal Analysis
- Design Example
- Amplifier Input and Output Impedances
# Basic Single BJT Amplifier Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>CE Amplifier</th>
<th>CC Amplifier</th>
<th>CB Amplifier</th>
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<tbody>
<tr>
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CE BJT amplifier => CS MOS amplifier  
CC BJT amplifier => CD MOS amplifier  
CB BJT amplifier => CG MOS amplifier  

VCVS  
CCCS
Common Collector (Emitter Follower) Amplifier

In the emitter follower, the output voltage is taken between emitter and ground. The voltage gain of this amplifier is nearly one – the output “follows” the input - hence the name: emitter “follower.”
Equivalent Circuits

\[
\begin{align*}
\frac{V_{CC}}{2} & = R_B = R_1 \parallel R_2 \\
R_B & = 50 \text{ k Ohm} \\
R_E & = 5.1 \text{ k Ohm} \\
V_O & = 6 \text{ V} \\
V_{CC} & = 12 \text{ V}
\end{align*}
\]
Multisim Bias Check

$$V_{Rb} = I_B R_B = \frac{I_E}{(\beta + 1)} R_B = 0.495 \, V$$

Identical results – as expected!
Follower Small Signal Analysis - Voltage Gain

Circuit analysis:

\[ v_s = (R_S + r_\pi) i_b + R_E i_e = (R_S + r_\pi + (\beta + 1) R_E) i_b \]

Solving for \( i_b \)

\[ i_b = \frac{v_s}{R_S + r_\pi + (\beta + 1) R_E} \]

\[ v_o = R_E i_e = R_E (1 + \beta) i_b \]

\[ v_o = \frac{R_E (\beta + 1) v_s}{R_S + r_\pi + (\beta + 1) R_E} \]

for Current Bias Design

replace \( R_E \) with \( r_o \| r_o = r_o / 2 >> R_E \)

\[ A_V = \frac{v_o}{v_s} = \frac{R_E r_o \| r_o}{R_S + r_\pi + (\beta + 1) R_E} \approx 1 \]
Small Signal Analysis – Voltage Gain - cont.

\[ \frac{v_o}{v_s} = \frac{R_E}{R_S + r_\pi (\beta + 1) + R_E} \]

Since, typically:

\[ \frac{R_S + r_\pi}{(\beta + 1)} \ll R_E \quad (\text{or } r_o || r_o = r_o / 2) \]

\[ A_V = \frac{v_o}{v_s} \approx \frac{R_E}{R_E} = 1 \]

Note: \( A_V \) is non-inverting
Quick Review

**CE Amplifier**

Voltage Gain ($A_V$)

Current Gain ($A_I$)

Input Resistance

Output Resistance

**CC Amplifier**

**CB Amplifier**

**ANSWERS:** Low, Moderate or High
Quick Review cont.

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VCVS

CCCS
Of What value is a Unity Gain Amplifier?

To answer this question, we must examine the small-signal output impedance of the amplifier and its power gain.
Emitter Follower Output Resistance

\[ i_x = -i_e = -(1 + \beta) i_b \Rightarrow i_b = \frac{-i_x}{1 + \beta} \]

\[ v_x = -i_b (R_S + r_\pi) = \frac{R_S + r_\pi}{1 + \beta} i_x \quad \text{where} \quad r_\pi \gg R_S \]

\[
\begin{align*}
R_{out} & = \frac{v_x}{i_x} = \frac{R_S + r_\pi}{1 + \beta} \approx \frac{r_\pi}{1 + \beta} = r_e = \frac{1}{g_m} = \frac{V_T}{I_C} \\
R_{out} & \approx r_e = \frac{2550}{100} = 25.5 \, \Omega \\
\text{Recall} \quad R_{in} & = r_{bg} = r_\pi + (\beta + 1) R_E
\end{align*}
\]

Assume:

\[ I_C = 1 \, mA \Rightarrow r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C} = 2500 \, \Omega \]

\[ \beta = 100 \quad R_S = 50 \, \Omega \]
Multisim Verification of $R_{out}$

Thevenin equivalent for the short-circuited emitter follower.

If $\beta = 200$, as for most good NPN transistors, $R_{out}$ would be lower - close to $12 \, \Omega$.

Multisim short circuit check

$(\beta = 100, \, v_o = v_s)$:

$$R_{out} = \frac{v_{oc}}{i_{sc}} = \frac{v_s(rms)}{i_{sc}(rms)} = \frac{1 \, V}{39.61 \, mA} = 22.25 \, \Omega$$
Emitter Follower Power Gain

Consider the case where a $R_L = 50 \, \Omega$ load is connected through an infinite capacitor to the emitter of the follower. Using its Thevenin equivalent:

$$v_o = \frac{R_L A_V v_s}{R_L || R_E + R_{out}} = \frac{50}{75} v_s = \frac{2}{3} v_s$$

$$i_o = \frac{A_V v_s}{R_{out} + R_L || R_E} = \frac{v_s}{75}$$

$$p_o = v_o i_o = \frac{2}{225} v_s^2$$

$$v_s \approx \frac{v_s}{5000}$$

$$R_E || R_L = 5.1 \, k\Omega || 50 \, \Omega \approx 50 \, \Omega$$

$$p_s = v_s i_s \approx \frac{1}{5000} v_s^2$$

$$A_{pwr} = \frac{p_o}{p_s} = \frac{2(5000)}{225} = 44.4 \gg 1$$
Split bias voltage drops about equally across the transistor $V_{CE}$ (or $V_{CB}$) and $V_{Re}$ (or $V_B$).

For simplicity, choose:

$$V_B = \frac{V_{CC}}{2} \implies R_1 = R_2$$

Then, choose/specify $I_E$, and the rest of the design follows:

$$R_E = \frac{V_E}{I_E} = \frac{V_{CC}/2 - 0.7}{I_E}$$

For an assumed $\beta = 100$:

As with CE bias design, stable op. pt.

$\implies R_B \ll (\beta + 1) R_E$, i.e.

$$R_B = R_1 || R_2 = \frac{R_1}{2} = \frac{(\beta + 1)}{10} R_E \approx 10 R_E$$

$$R_1 = R_2 = 20 R_E$$
Typical Design - Cont.

Given: \( R_{\text{out}} = r_e = 25 \Omega \)
\( V_{CC} = 12 \, V \)

And the rest of the design follows

\[ I_E \approx I_C = \frac{V_T}{r_e} = 1 \, mA \]

\[ R_E = \frac{V_E}{I_E} = \frac{12/2 - 0.7}{10^{-3}} = 5.3 \, k\Omega \]

Use standard sizes

\[ R_E = 5.1 \, k\Omega \]
\[ R_1 = R_2 = 100 \, k\Omega \]
Use the base current expression:

\[ v_{bg} = r_\pi i_b + R_E i_e = (r_\pi + (\beta + 1) R_E) i_b \]

\[ i_b = \frac{v_{bg}}{r_\pi + (\beta + 1) R_E} \]

\[ r_{bg} = \frac{v_{bg}}{i_b} = r_\pi + (\beta + 1) R_E \approx (\beta + 1) R_E = 101 \cdot 5.1 \, k\Omega = 515 \, k\Omega \]

To obtain the base to ground resistance of the transistor: This transistor input resistance is in parallel with \( R_B = 50 \, k\Omega \), forming the total amplifier input resistance:

\[ R_{in} = R_S + R_B \| r_{bg} \approx R_B \| r_{bg} = \frac{515}{515 + 50} 50 \, k\Omega = 45.6 \, k\Omega \approx R_B = 50 \, k\Omega \]
Choose $C_{in}$ such that its reactance is $\leq 1/10$ of $R_B$ at $f_{min}$:

$$\frac{1}{2\pi f C_{in}} = \frac{R_B}{10}$$

$$C_{in} \geq \frac{10}{2\pi f_{min} R_B}$$

Assume $f_{min} = 20$ Hz with $R_B = 50 \, k\Omega$

$$C_{in} \geq \frac{10}{2\pi \cdot 20 \cdot 50 \cdot 10^3} = 1.59 \, \mu F$$

Pick $C_{in} = 3.3 \, \mu F$, the nearest standard value in the Detkin Lab. We could be (unnecessarily) more precise and include $r_{bg}$ and $R_s$ as part of the total resistance in the loop.
Final Design

\[ V_s \quad \text{50 Ohm} \]
\[ R_s \]
\[ C_{in} \quad 3.3 \text{ uF} \]
\[ R_1 \quad 100 \text{ k Ohm} \]
\[ R_2 \quad 100 \text{ k Ohm} \]
\[ R_E \quad 5.1 \text{ k Ohm} \]
\[ V_{CC} \quad 12 \text{ V} \]
**Multisim Simulation Results**

20 Hz Data

\[ A_v = 0.995 \]

1 kHz Data
The Common Base Amplifier

Voltage Bias Design

Current Bias Design
Common Base Configuration

Both voltage and current biasing follow the same rules as those applied to the common emitter amplifier.

As before, insert a blocking capacitor in the input signal path to avoid disturbing the dc bias.

The common base amplifier uses a bypass capacitor – or a direct connection from base to ground to hold the base at ground for the signal only!

RECALL: The common emitter amplifier (except for intentional $R_E$ feedback) holds the emitter at signal ground, while the common collector circuit does the same for the collector.
We keep the same bias that we established for the gain of 10 common emitter amplifier.

All that we need to do is pick the capacitor values and calculate the circuit gain.
Mid-band Small Signal Analysis

**Input Impedance**

\[ v_{Re} = r_e \parallel R_E i_s \]

\[ Z_{in} = \frac{v_{Re}}{i_s} = r_e \parallel R_E \approx r_e = \frac{V_T}{I_C} \]

\[ Z_{out} = \frac{v_o}{i_c} = R_C \parallel r_o \]

**Current Gain**

\[ A_i = \frac{i_c}{i_e} = \alpha \approx 1 \]

**Voltage Gain**

\[ v_s = -i_e R_S - r_e \parallel R_E i_e \]

\[ v_o = -R_C i_c = -\alpha R_C i_e = \frac{1}{\alpha} \frac{R_C}{R_S + r_e \parallel R_E} v_s \]

\[ A_v = \frac{v_o}{v_s} \approx \frac{1}{\alpha} \frac{R_C}{R_S + r_e} \]
Common Base Small Signal Analysis - $C_{in}$

Determine $C_{in}$: (let $C_b = \infty$)

$$v_{Re} = \frac{R_E || r_e + R_s}{R_E || r_e + R_s + \frac{1}{j2\pi f C_{in}}} v_s$$

$$r_e = \frac{r_{\pi}}{1 + \beta}$$

ideally

$$v_{Re} = \frac{R_E || r_e}{R_E || r_e + R_s} v_s \quad \text{for } f \geq f_{\text{min}}$$

$$\frac{1}{2\pi f_{\text{min}} C_{in}} \ll R_s + R_E || r_e$$

$$\Rightarrow$$

$$\frac{1}{2\pi f_{\text{min}} C_{in}} \Rightarrow R_s + R_E || r_e = \frac{1}{2\pi f_{\text{min}} C_{in}} = \frac{R_s + r_e}{10} \Rightarrow C_{in} = \frac{10}{2\pi f_{\text{min}}(R_s + r_e)}$$

NOTE: $R_B$ is shorted by $C_b = \infty$
Determine $C_{in}$ cont.

A suitable value for $C_{in}$ for a 20 Hz $f_{min}$ with $r_e = 25 \, \Omega$ and $R_S = 50 \, \Omega$:

$$2 \pi f_{min} C_{in} (R_S + r_e) \gg 1 \Rightarrow C_{in} \geq \frac{10}{2 \pi f_{min} (R_S + r_e)} = \frac{10}{2 \pi 20 \cdot 75} \, F$$

$$C_{in} = \frac{10}{125.6 \cdot 75} \approx 1062 \, \mu F !$$

Not Practical!

Must choose smaller value of $C_{in}$.

Choose:  

$$2 \pi f_{min} C_{in} (R_S + r_e) = 1$$

$$C_{in} = \frac{1}{125.6 \cdot 75} \approx 106.2 \, \mu F$$
Small-signal Analysis - $C_b$

Determine $C_b$: (let $C_{in} = \infty$)

Note the ac reference current reversals (due to $v_s$ polarity!)

\[
\begin{align*}
R_E \| (r_e + \frac{1}{j 2\pi f C_b(\beta+1)}) \\
R_E \| (r_e + \frac{1}{j 2\pi f C_b(\beta+1)}) + R_S \\
\end{align*}
\]

\[
\begin{align*}
v_{Re} &= \frac{R_E \| r_e}{R_E \| (r_e + R_S)} v_s \quad \text{for } f \geq f_{min} \\
\end{align*}
\]

\[
\begin{align*}
\frac{1}{2\pi f_{min} C_b(\beta+1)} \ll r_e \Rightarrow \frac{1}{2\pi f_{min} C_b(\beta+1)} &= \frac{r_e}{10} \Rightarrow C_b = \frac{10}{2\pi f_{min} r_e (\beta+1)} \\
\end{align*}
\]
Choose (conservatively):

\[ C_b = \frac{10}{2\pi f_{\text{min}} \left( (\beta + 1) r_e \right)} F \]

for \( f_{\text{min}} = 20 \text{ Hz} \)

i.e.

\[ C_b = \frac{10}{2\pi 20 \left( (100)(25) \right)} = 31.8 \mu F \]
Multisim Simulation

\[ A_v = \frac{v_o}{v_s} = \frac{1}{\alpha} \frac{R_C}{R_s + r_e} \approx \frac{R_C}{R_s + r_e} = \frac{4700}{50 + 25} = 62.7 \]
Multisim Frequency Response

20 Hz response

vertical axis is a linear scale

1 kHz Response

\[ A_{v(sim)} = 63.3 > A_{v(\text{theory})} = 62.7 \]

\( \delta < 1 \% \)