Common Base BJT Amplifier

Common Collector BJT Amplifier

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**Basic Single BJT Amplifier Features**

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CE BJT amplifier => CS MOS amplifier  
CC BJT amplifier => CD MOS amplifier  
CB BJT amplifier => CG MOS amplifier
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.”
Split bias voltage drops about equally across the transistor $V_{CE}$ (or $V_{CB}$) and $V_{Re}$ (or $V_B$).

For simplicity, choose:

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

Then, choose/specified $I_E$, 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. $\Rightarrow R_B \ll (\beta + 1) R_E$, i.e.

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

$$R_1 = R_2 = 20 R_E$$
Typical Design

Choose: \( I_E = 1 \text{ mA} \)
\[ V_{CC} = 12 \text{ V} \]

And the rest of the design follows immediately:

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

Use standard sizes

\[
R_E = 5.1 \text{ k}\Omega
\]
\[ R_1 = R_2 = 100 \text{ k}\Omega \]
**Equivalent Circuits**

- $V_{CC} / 2$
- $R_B = R_1 \parallel R_2$
- $V_{CC}$
- $V_b = 6\text{ V}$
- $V_{CC} / 2$
- $R_s = 50\text{ k Ohm}$
- $R_b$
- $v_{out}$
- $v_{sig}$
- $100\text{ k Ohm}$
- $5.1\text{ k Ohm}$
Multisim Bias Check

\[ V_{RB} = I_B R_B = \frac{I_E}{(\beta + 1)} R_B = 0.495 \text{ V} \]

Identical results – as expected!
Small signal mid-band circuit - where $C_B$ has negligible reactance (above $\omega_{\text{min}}$). Thevenin circuit consisting of $R_S$ and $R_B$ shows effect of $R_B$ negligible, since it is much larger than $R_S$. 

$$V_{\text{sig}} = \frac{R_B}{R_B + R_S} \approx \frac{50}{50.05} \approx 1$$

$$R_{TH} = R_S \parallel R_B = \frac{50}{50.05} \approx R_S$$
Follower Small Signal Analysis - Voltage Gain

Circuit analysis:

\[ v_{sig} = \left( R_S + r_\pi + (\beta + 1) R_E \right) i_b \]

Solving for \( i_b \):

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

\[ v_{out} = R_E i_e = R_E (1 + \beta) i_b \]

\[ v_{out} = \frac{R_E (\beta + 1) v_{sig}}{R_S + r_\pi + (\beta + 1) R_E} \]

\[ A_V = \frac{v_{out}}{v_{sig}} = \frac{R_E v_{sig}}{R_S + r_\pi + (\beta + 1) R_E} \approx 1 \]
Small Signal Analysis – Voltage Gain - cont.

\[
\frac{v_{\text{out}}}{v_{\text{sig}}} = \frac{R_E}{R_S + r_\pi + R_E} \frac{(\beta + 1)}{R_S + r_\pi + R_E}
\]

Since, typically:

\[
\frac{R_S + r_\pi}{(\beta + 1)} \ll R_E
\]

Note: \(A_V\) is non-inverting
Use the base current expression:

$$v_{bg} = r_\pi i_b + R_E i_E = (r_\pi + (\beta + 1)) i_b$$

$$i_b = \frac{V_{bg}}{r_\pi + (\beta + 1) R_E}$$

To obtain the base to ground resistance of the transistor:

This transistor input resistance is in parallel with the 50 kΩ $R_B$, forming the total amplifier input resistance:

$$R_{in} = R_S + R_B \| r_{bg} \approx R_B \| r_{bg} = \frac{515}{(515 + 50)} \times 50 \, k\Omega = 45.6 \, k\Omega$$
$C_B$ – Selection cont.

Choose $C_B$ such that its reactance is $\leq 1/10$ of $R_{in}$ at $\omega_{min}$:

$$\frac{1}{\omega C_B} = \frac{R_{in}}{10}$$

$$C_B \geq \frac{10}{\omega_{min} R_{in}}$$

$$C_B \geq \frac{10 \cdot 10^{-7}}{1.25 \cdot 0.46} \approx 1.73 \mu F$$

Assume the lowest frequency is $20$ Hz:

$$\omega_{min} = 2\pi \cdot 20 \approx 125 = 1.25 \cdot 10^2$$

$$\beta = 100$$

$$R_{in} \approx 46 \, k\Omega$$

Pick $C_B = 2 \, \mu F$ (two $1 \, \mu F$ caps in parallel), the nearest standard value in the RCA Lab. We could be (unnecessarily) more precise and include $R_s$ as part of the total resistance in the loop. It is very small compared to $R_{in}$. 
Final Design

![Circuit Diagram]

- $C_b = 2.0 \mu F$
- $R_s = 50 \Omega$
- $R_1 = 100 \, k\Omega$
- $R_2 = 100 \, k\Omega$
- $R_e = 5.1 \, k\Omega$
- $V_{cc} = 12 \, V$
- $V_{out}$

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Multisim Simulation Results

20 Hz. Data

1 Khz. Data
Of What value is a Unity Gain Amplifier?

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

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

\[ v_x = -i_b (R_s + r_\pi) = \frac{R_s + r_\pi}{1 + \beta} i_x \]

\[ R_{out} = \frac{v_x}{i_x} = \frac{R_s + r_\pi}{1 + \beta} \approx \frac{r_\pi}{1 + \beta} \]

\( R_{out} \) is the Thevenin resistance looking into the open-circuit output.

Assume:

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

\[ \beta = 100 \quad R_S = 50 \Omega \]

\[ R_{out} \approx \frac{2550}{100} = 25.5 \Omega \]

\( R_B = 50 \text{ k}\Omega \gg R_S \)
Multisim Verification of $R_{out}$

Thevenin equivalent for the short-circuited emitter follower. If $\beta$ was 200, as for most good NPN transistors, $R_{out}$ would be lower - close to 12 $\Omega$.

Multisim short circuit check

$\beta = 100$, $v_{out} = v_{sig}$:

$$R_{out} = \frac{v_{oc}}{i_{sc}} = \frac{A_{V} v_{sig(rms)}}{i_{sc(rms)}} = \frac{1}{0.0396} = 25.25 \Omega$$
**Equivalent Circuits with Load $R_L$**

\[ R_{\text{in}} = R_S + r_\pi + (\beta + 1) R_E \parallel R_L \approx (\beta + 1) R_L \]

\[ R_{\text{out}} = \frac{V_{\text{sig}}(\text{rms})}{i_{\text{sc}}(\text{rms})} = \frac{1}{0.0396} = 25.25 \, \Omega \]
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 we designed. Using its Thevenin equivalent:

$$V_{load} = \frac{R_L A_V v_{sig}}{R_L + R_{out}} = \frac{50}{75} v_{sig} = \frac{2}{3} v_{sig}$$

$$i_{load} = \frac{A_V v_{sig}}{R_{out} + R_L} = \frac{v_{sig}}{75}$$

$$P_{load} = V_{load} i_{load} = \frac{2}{225} v_{sig}^2$$

50\,\Omega\,\text{load is in parallel with } 5.1k\Omega\,R_E\,\text{and dominates:}$$i_{sig} = i_b = \frac{v_{sig}}{R_{in}} \approx \frac{v_{sig}}{(\beta+1)\,R_E || R_L} \approx \frac{v_{sig}}{101 \cdot 50}$$

$$p_{sig} = v_{sig} i_{sig} \approx \frac{1}{5000} v_{sig}^2$$

$$G_{pwr} = \frac{p_{load}}{p_{sig}} = \frac{2(5000)}{225} = 44.4 \gg 1$$
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!

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.
**Common Base Small Signal Analysis - \( C_{\text{IN}} \)**

Determine \( C_{\text{IN}} \): (let \( C_B = \infty \))

Find a equivalent impedance for the input circuit, \( R_S \), \( C_{\text{IN}} \), and \( R_{E2} \):

\[
\begin{align*}
V_{Re2} &= \frac{R_{E2} \ || \ r_e}{R_{E2} \ || \ r_e + R_S + \frac{1}{j \omega C_{\text{IN}}}} \\
V_{sig} &= \frac{r_e}{1 + \beta} \\
\end{align*}
\]

**ideally**

\[
V_{Re2} = \frac{R_{E2} \ || \ r_e}{R_{E2} \ || \ r_e + R_S} \quad \text{for} \quad \omega \geq \omega_{\text{min}}
\]

\[
\frac{1}{\omega_{\text{min}} C_{\text{IN}}} \ll \frac{r_e}{R_S + R_{E2}} \Rightarrow \frac{r_e}{\omega_{\text{min}} C_{\text{IN}}} = \frac{R_S + r_e}{10} \Rightarrow C_{\text{IN}} = \frac{10}{\omega_{\text{min}}(R_S + r_e)}
\]
Determine $C_{IN}$ cont.

A suitable value for $C_{IN}$ for a 20 Hz lower frequency:

$$\omega_{\text{min}} C_{IN} (R_s + r_e) \gg 1 \Rightarrow C_{IN} \geq \frac{10}{2 \pi \omega_{\text{min}} (R_s + r_e)} = \frac{10}{2 \pi 20 \cdot 75} \text{ F}$$

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

Not too practical!

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

1. Choose: $\omega_{min} C_{IN} (R_s + r_e) = 1$

or

2. Choose larger $\omega_{min}$
Small-signal Analysis - $C_B$

Determine $C_B$: (let $C_{IN} = \infty$)

Note the reference current reversals (due to $v_{sig}$ polarity)!

$v_{sig} = R_S i'_e + \left( r_\pi + \frac{1}{j \omega C_B} \right) i'_b$

$v_{sig} = R_S i'_e + \left( r_\pi + \frac{1}{j \omega C_B} \right) \frac{i'_e}{\beta+1}$

$\beta + 1 \quad v_{sig}$

$\frac{\beta + 1}{(\beta + 1) R_S + r_\pi + \frac{1}{j \omega C_B}}$

Determine $Z_{in} = \frac{v_{sig}}{i'_e}$
Determine – $C_B$

$$i'_e = \frac{\beta + 1}{(\beta + 1) R_S + r_\pi + \frac{1}{j\omega C_B}} V_{\text{sig}}$$

$$i'_e = \frac{V_{\text{sig}}}{R_S + \frac{1}{\beta + 1} \left( r_\pi + \frac{1}{j\omega C_B} \right)}$$

$$Z_{in} = \frac{V_{\text{sig}}}{i'_e} = R_S + \frac{1}{\beta + 1} \left( r_\pi + \frac{1}{j\omega C_B} \right)$$

ideally $Z_{in} \approx R_S + \frac{r_\pi}{\beta + 1} \Rightarrow \frac{1}{\omega C_B} \ll (\beta + 1) R_S + r_\pi$ for $\omega \geq \omega_{\text{min}}$
Determine - $C_B$ cont.

For $\omega \geq \omega_{\text{min}}$

$$Z_{in} \approx R_S + \frac{r_\pi}{\beta + 1} \Rightarrow \frac{1}{\omega C_B} \ll (\beta + 1) R_S + r_\pi$$

Choose:

$$C_B \geq \frac{10}{\omega_{\text{min}}(\beta + 1) R_S + r_\pi}$$

i.e.

$$C_B \geq \frac{10}{2 \pi 20 \left( (100 + 1)50 + 2500 \right)} = 10.5 \mu F$$
Small-signal Analysis – Voltage Gain

\[ i'_e \approx \frac{1}{R_S + \frac{r_\pi}{\beta + 1}} \]

\[ v_{sig} = \frac{1}{R_S + r_e} v_{sig} \]

\[ v_{out} = R_C i'_e = \alpha R_C i'_e = \frac{\beta}{\beta + 1} \frac{R_C}{R_S + r_e} v_{sig} \]

\[ A_V = \frac{v_{out}}{v_{sig}} = \frac{\beta}{\beta + 1} \frac{R_C}{R_S + r_e} = \frac{100}{101} \frac{5100}{50 + 25} \approx 67 \]

Assume: \( C_B = C_{IN} = \infty \)
Multisim Simulation

[Image of a circuit diagram with labeled components such as R1, R2, Rc, Rs, Re, Cin, Cb, Vcc, and vsig, including values like 51 k Ohm, 5100 Ohm, 5.6 k Ohm, 510, and 1062 uF and 12 V.]
Multisim Frequency Response

20 Hz. response

1 KHZ. Response