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

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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.”
**Emitter Follower Biasing**

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/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.

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

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

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

Given: \( I_E = 1 \, mA \)
\( V_{CC} = 12 \, V \)

And the rest of the design follows immediately:

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

Use standard sizes:

\( R_E = 5.1 \, k\Omega \)

\( R_1 = R_2 = 100 \, k\Omega \)
Equivalent Circuits

\[ V_{CC}/2 = R_B = R_1 || R_2 \]

\[ R_B = 50 \text{ k Ohm} \]

\[ R_E = 5.1 \text{ k Ohm} \]

\[ V_s = 6 \text{ V} \]

\[ V_{CC} = 12 \text{ V} \]
Multisim Bias Check

Identical results – as expected!

\[ V_{Rb} = I_B R_B = \frac{I_E}{(\beta + 1)} R_B = 0.495 \, V \]
Emitter Follower Small Signal Circuit

Mid-band equivalent circuit:

\[ v'_s = \frac{R_B}{R_B + R_S} \quad v_s = \frac{50}{50.05} \quad v_s \approx v_s \]

\[ R_{TH} = R_S \parallel R_B = \frac{50}{50.05} \quad R_S \approx R_S \]

Small signal mid-band circuit - where \( C_{in} \) has negligible reactance (above \( f_{min} \)). Thevenin circuit consisting of \( R_S \) and \( R_B \) shows effect of \( R_B \) negligible, since it is much larger than \( R_S \).
Follower Small Signal Analysis - Voltage Gain

Circuit analysis:

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

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 \( r_o \parallel r_o = r_o / 2 >> R_E \)

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

\[
\frac{v_o}{v_s} = \frac{R_E}{R_S + r_\pi + R_E} + R_E
\]

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
Use the base current expression:

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

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

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

To obtain the base to ground resistance of the transistor:

This transistor input resistance is in parallel with the 50 kØ \( R_B \), forming the total amplifier input resistance:

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

\[
\frac{1}{2\pi f C_{in}} = \frac{R_B || r_{bg}}{10}
\]

\[
C_{in} \geq \frac{10}{2\pi f_{min} R_B || r_{bg}}
\]

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

with \( R_B || r_{bg} \approx 50 \text{ k}\Omega \)

\[
C_{in} \geq \frac{10}{2\pi \cdot 20 \cdot 50 \cdot 10^3} \approx 1.59 \mu F
\]

Pick \( C_{in} = 3.3 \mu F \), the nearest standard value in the Detkin Lab. We could be (unnecessarily) more precise and include \( R_s \) as part of the total resistance in the loop. It is very small compared to \( R_{in} \).
Final Design

The diagram shows a circuit with the following components:

- **$C_{in}$**: 3.3 μF
- **$R_s$**: 50 Ohm
- **$R_1$**: 100 k Ohm
- **$R_2$**: 100 k Ohm
- **$R_E$**: 5.1 k Ohm
- **$V_{CC}$**: 12 V

The circuit diagram illustrates the interconnection of these components, indicating how they interact within the system.
Multisim Simulation Results

20 Hz Data

1 kHz Data

$A_v = 0.995$
## Quick Review

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**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**

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

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

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

Assume:

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

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

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

$(\beta = 100, \, v_{oc} = v_s)$:

$$R_{out} = \frac{v_{oc}}{i_{sc}} = A_v \frac{v_{s(rms)}}{i_{sc(rms)}} = \frac{1}{0.0396} = 25.25 \, \Omega$$
Equivalent Circuits with Load $R_L$

$$R_{in} = r_{bg} = R_S + r_{\pi} + (\beta + 1) R_E \parallel R_L \approx \beta R_E \parallel R_L$$

$$R_{out} = r_{eg}$$

$$R_{out} = \frac{A_v v_s(rms)}{i_{sc(rms)}} = \frac{1}{0.0396} = 25.25 \Omega$$
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:

\[
\begin{align*}
    v_o &= \frac{R_L A_V v_s}{R_L + R_{out}} = \frac{50}{75} v_s = \frac{2}{3} v_s \\
    i_o &= \frac{A_V v_s}{R_{out} + R_L} = \frac{v_s}{75} \\
    p_o &= v_o i_o = \frac{2}{225} v_s^2 \\
    R_E || R_L &= 5.1k\Omega || 50\Omega \approx 50\Omega \\
    i_s = i_b &= \frac{v_s}{R_{in}} \approx \frac{v_s}{(\beta+1)R_E||R_L} \approx \frac{v_s}{101 \cdot 50} \approx \frac{v_s}{5000} \\
    p_s &= v_s i_s \approx \frac{1}{5000} v_s^2 \\
    A_{pwr} &= \frac{p_o}{p_s} = \frac{2(5000)}{225} = 44.4 \gg 1
\end{align*}
\]
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 - $C_{in}$

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

Find a equivalent impedance for the input circuit, $R_S$, $C_{in}$, and $R_E$:

$$v_{Re2} = \frac{R_E || r_e}{R_E || r_e + R_S + \frac{1}{j2\pi f C_{in}}} v_s$$

for $f \geq f_{min}$

\[
C_{in} = \frac{10}{2\pi f_{min}(R_S + r_e)}
\]
Determine $C_{in}$ cont.

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

\[
2\pi f_{\text{min}} C_{in}(R_s + r_e) \gg 1 \Rightarrow C_{in} \geq \frac{10}{2\pi f_{\text{min}}(R_s + r_e)} = \frac{10}{2\pi 20 \cdot 75} F
\]

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

Not too Practical!

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

1. Choose: \[2\pi f_{\text{min}} C_{in}(R_s + r_e) = 1\]

or

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

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

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

\[
\begin{align*}
v_s &= R_S i_e' + \left( r_\pi + \frac{1}{j \omega C_B} \right) i_b' \\
v_s &= R_S i_e' + r_e i_e' + \left( \frac{1}{j \omega C_B (\beta + 1)} \right) i_e'
\end{align*}
\]

Determine $Z_{in} = \frac{v_s}{i_e'}$

\[
Z_{in} = \frac{v_s}{i_e'} = R_S + r_e + \frac{1}{j \omega C_B (\beta + 1)}
\]
Determine – $C_B$

$$Z_{in} = \frac{v_s'}{i_e'} = R_S + r_e + \frac{1}{j \omega C_B (\beta + 1)}$$

ideally

$$Z_{in} \approx R_S + r_e \quad f \geq f_{min}$$

or

$$\frac{1}{2 \pi f C_B} \ll (\beta + 1)(R_S + r_e) \quad f \geq f_{min}$$

Choose (conservatively):

$$C_B = \frac{10}{2 \pi f_{min} ((\beta + 1)(R_S + r_e))^F}$$
Determine - $C_B$ cont.

Choosing (conservatively):

$$C_B = \frac{10}{2\pi f_{\text{min}} \left( (\beta + 1) (R_S + r_e) \right)} \ F$$

for $f_{\text{min}} = 20 \ \text{Hz}$

$$C_B = \frac{10}{2\pi \times 20 \times ((100)(50 + 25))} = 10.6 \mu F$$

i.e.

Choose (less conservatively):

$$C_B \geq \frac{1}{2\pi \times 20 \times ((100)(50 + 25))} = 1.06 \mu F$$
Small-signal Analysis – Voltage Gain

\[
i_e' \approx \frac{1}{R_s + r_e} v_s
\]

\[
v_{out} = R_C i_c' = \alpha R_C i_e' = \frac{\beta}{\beta + 1} \frac{R_C}{R_s + r_e} v_s
\]

\[
A_V = \frac{v_{out}}{v_s} = \frac{\beta}{\beta + 1} \frac{R_C}{R_s + r_e} = \frac{100}{101} \frac{4700}{50 + 25} = 62.1
\]

Assume: \( C_B = C_{in} = \infty \)

\( R_E \parallel r_e \approx r_e \)

Ignore \( R_B \)
Multisim Simulation
Multisim Frequency Response

20 Hz response

1 kHz Response

$A_{v(sim)} = 63.3 > A_{v(theory)} = 62.1$