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.”
**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:

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

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.

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

$$R_1 = R_2 = 20 R_E$$
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

\[ V_{CC}/2 = R_{E} \]

\[ R_B = R_1 \parallel R_2 \]

\[
\begin{align*}
V_s & \quad 100 \text{ k}\Omega \\
R_S & \quad 100 \text{ k}\Omega \\
R_1 & \quad i_C \\
V_B & \quad 12 \text{ V} \\
\end{align*}
\]

\[
\begin{align*}
C_B & \quad V_{CC} \\
R_B & \quad 50 \text{ k}\Omega \\
R_E & \quad 5.1 \text{ k}\Omega \\
V_{CC}/2 & \quad 6 \text{ V} \\
\end{align*}
\]
Multisim Bias Check

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

Identical results – as expected!
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 \( C_B \) 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 \( r_o \parallel r_o = r_o / 2 >> R_E \)

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

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

Since, typically:

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

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

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

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

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

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:

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

\[
\frac{1}{2\pi f C_B} = \frac{R_{in}}{10}
\]

\[
C_B \geq \frac{10}{2\pi f_{min} R_{in}}
\]

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 $R_{in}$.

Assume $f_{min} = 20$ Hz

with $R_{in} \approx 50 k \Omega$
Final Design

\[ v_s \]

\[ R_S \quad 50 \text{ Ohm} \]

\[ C_B \quad 2.0 \text{ uF} \]

\[ R_1 \quad 100 \text{ k Ohm} \]

\[ R_2 \quad 100 \text{ k Ohm} \]

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

\[ V_{CC} \quad 12 \text{ V} \]
Multisim Simulation Results

20 Hz Data

1 kHz Data
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

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

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

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

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

Assume:

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

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

\( R_{out} \approx \frac{2550}{100} = 25.5 \Omega \)
Multisim Verification of $R_{\text{out}}$

Thevenin equivalent for the short-circuited emitter follower.

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

Multisim short circuit check ($\beta = 100, v_o = v_s$):

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

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

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

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

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

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

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

$$i_s = i_b = \frac{v_s}{R_{in} (\beta + 1) R_E || R_L} \approx \frac{v_s}{101 \cdot 50} \approx \frac{v_s}{5000}$$

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

$$A_{pwr} = \frac{p_o}{p_s} = \frac{2(5000)}{225} = 44.4 \gg 1$$
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.
Determine $C_{IN}$: (let $C_B = \infty$)

Find a equivalent impedance for the input circuit, $R_S$, $C_{in}$, and $R_{E2}$:

$$v_{Re2} = \frac{R_{E2} || r_e}{R_{E2} || r_e + R_S + \frac{1}{j2\pi f C_{in}}} v_s$$

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

ideally

$$v_{Re2} = \frac{R_{E2} || r_e}{R_{E2} || r_e + R_S} v_s$$

for $f \geq f_{min}$

$$\frac{1}{2\pi f_{min} C_{in}} \ll R_S + \frac{r_e}{R_{E2} || r_e} \Rightarrow \frac{1}{2\pi f_{min} C_{in}} = \frac{R_S + r_e}{10} \Rightarrow C_{in} = \frac{10}{2\pi f_{min} (R_S + r_e)}$$

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

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

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

$$C_{in} = \frac{10}{125.6 \cdot 75} \approx 1062 \mu F! \quad \text{Not too Practical!}$$

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!)

$$v_s = R_S i_e' + \left( r_{\pi} + \frac{1}{j \omega C_B} \right) i_b'$$

$$v_s = R_S i_e' + \left( r_{\pi} + \frac{1}{j \omega C_B} \right) \frac{i_e'}{\beta + 1}$$

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

$$i_e' = \frac{\beta + 1}{(\beta + 1) R_S + r_{\pi} + \frac{1}{j \omega C_B}} v_s$$
Determine – $C_B$

$$i'_e = \frac{\beta + 1}{(\beta + 1) R_S + r_\pi + \frac{1}{j 2\pi f C_B}} v_s$$

**ideally**

$$Z_{in} \approx \frac{(\beta + 1) R_S + r_\pi}{\beta + 1} = R_S + \frac{r_\pi}{\beta + 1}$$

or

$$\frac{1}{2\pi f C_B} \ll (\beta + 1) R_S + r_\pi$$

Choose (conservatively):

$$C_B \geq \frac{10}{2\pi f_{\min} (\beta + 1) R_S + r_\pi} F$$

**ignore $R_B^*$**

$R_{E2} >> R_S$

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Determine - $C_B$ cont.

Choosing (conservatively):

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

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

$$C_B \geq \frac{10}{2 \pi 20 \left( (100) 50 + 2500 \right)} = 10.6 \mu F$$

i.e.

Choose (less conservatively):

$$C_B \geq \frac{1}{2 \pi 20 \left( (100) 50 + 2500 \right)} = 1.06 \mu F$$
Small-signal Analysis – Voltage Gain

\[ i_e' \approx \frac{1}{r_{\pi}} v_s = \frac{1}{R_S + r_e} v_s \]

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

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

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

\( R_{E2} >> R_S \)

ignore \( R_B \)
Multisim Simulation

\[ C_b = 10.6 \, \text{uF} \]
\[ R_1 = 51 \, \text{kOhm} \]
\[ R_c = 5100 \, \text{Ohm} \]
\[ R_2 = 5.6 \, \text{kOhm} \]
\[ R_s = 50 \, \text{Ohm} \]
\[ R_e = 610 \, \text{Ohm} \]
\[ V_{cc} = 12 \, \text{V} \]
Multisim Frequency Response

20 Hz response

1 kHz Response