Common Emitter BJT Amplifier
Adding a signal source to the single power supply bias amplifier

Desired effect – addition of bias and signal sources

Starting point - single dc source
Wrong Way to Combine Sources

Source with low output impedance upsets bias.

Thevenin equivalent at base:
Wrong Way - Continued

To analyze,
1. Isolate base circuit,
2. Use superposition,
3. Find Thevenin equivalent for the base bias source, $V_B$:

$$V_{th} = \frac{50}{20000 + 50} V_B \approx \frac{5}{2000} V_B \quad (v_s = 0)$$

$$R_{th} = R_B' = R_B \parallel R_S = \frac{50 \cdot 20000}{50 + 20000} \approx 50 \Omega$$

The signal source effectively “shorts out” the bias source!

The signal source $v_s$ is essentially unaffected by the bias source $V_B$. (Why? What is its Thevenin equivalent?)
The Right Way – Use a “Blocking” Capacitor

1. Capacitor $C_b$ is an OPEN at dc and $R_S$ does not affect the bias!
2. $C_b$ charges to the dc bias source, $V_B$, to satisfy Kirchoff's voltage law.
3. The dc bias is in series with the signal source $v_s$, i.e. $v_s = V_B + v_s$

DESIGN GOAL: for $f \geq f_{\text{min1}}$, set the value of $C_b$ so that its ac voltage drop $v_{Cb}$ is negligible at and above the low frequency cutoff at say $f_{\text{min1}}$. 

For convenience let's continue to use the “base bias Thevenin equiv”.

\[ i_{C_b} = \frac{v_{C_b}}{C_b} \]

\[ v_{C_b} = V_{bg} + v_s \]

\[ V_{cc} = V_B + V_s \]

\[ V_{bg} = 4.7 \text{ V} \]

\[ V_s = 1 \text{ V/1 kHz/0 Deg} \]

\[ R_s = 50 \text{ Ohm} \]

\[ R_b = 20 \text{ kOhm} \]

\[ R_c = 4 \text{ kOhm} \]

\[ V_{cc} = 12 \text{ V} \]
Blocking Capacitor Selection

Using superposition, for small-signal let $V_B = 0$.

$$i_e = i_b + \beta i_b$$

$$r_{bg} = \frac{v_{bg}}{i_b}$$

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

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

Use the small signal equivalent circuit and superposition to estimate the input resistance of the transistor.
Capacitor Selection- continued

The signal source “sees” the 20 kΩ bias source resistance in parallel with . So the signal source equivalent circuit is:

\[ r_{bg} \approx 100 \, R_E = 400 \, k\Omega \]

Therefore:

\[ R_B \parallel r_{BG} = \frac{400}{420} \approx 20 \approx 20 \, k\Omega = R_B \]

The capacitor voltage drop is:

\[ v_{Cb} = \frac{1}{j \omega C_b} i_{Cb} \]

Where the capacitor current is:

\[ i_{Cb} \approx \frac{v_s}{R_B + \frac{1}{j \omega C_b}} \]

\[ \Rightarrow \quad v_{Cb} \approx \frac{v_s}{j \omega C_b R_B + 1} \]

Goal: \( \omega C_b R_B \gg 1 \)
CONSERVATIVE DESIGN GOAL: Choose $C_b$ for negligible voltage drop at $v_{Cb}$ for $f \geq f_{\text{min} 1}$, i.e.

$$\left| v_{Cb} \right| \approx \left| \frac{v_s}{j \omega C_b R_B + 1} \right| \leq \frac{v_s}{10}$$

for $f \geq f_{\text{min} 1}$

OR

DESIGN GOAL: Choose $C_b$ so that $f_{R BC_b} = 0.1 f_{\text{min} 1}$, i.e.

$$f_{Cb} = \frac{1}{2 \pi C_b R_B} = 0.1 f_{\text{min} 1} \Rightarrow C_b = \frac{10}{2 \pi f_{\text{min} 1} R_B}$$
Capacitor Selection - continued

Select the LOWEST frequency of interest. This sets the lower bound on $C_b$. Using $f_{min1} = 20$ Hz frequency for our example circuit:

$$2\pi f_{min1} = 2\pi \cdot 20 \approx 6.28 \cdot 20 = 125.6 \text{ sec}^{-1}$$

$$C_{b-min} = \frac{10}{125.6 \cdot 20 \cdot 10^3} = \frac{10^{-6}}{0.25} = 4 \, \mu F$$

ANY capacitor larger than $4 \, \mu F$ will also do the job!
Common Emitter Unity Gain Amplifier

How can we achieve reasonable gain with this circuit?

Solution: Split $R_E$ and use capacitor bypassing.
Bypass for Gain

**Procedure:**

1. Split the emitter resistor in two. Later, we will show that the voltage gain will be close to \(-\frac{R_C}{R_{E1}}\).

2. Bypass \(R_{E2}\) with a capacitor \(C_{byp}\) that looks like a near “short circuit” at some suitable low frequency \((f_{min2} \geq f_{min1})\).

\[ |v_{ZE2}| \ll |v_{RE1}| \text{ for } f \geq f_{min2} \]

\[
\begin{align*}
Z_{E2} &= R_{E2} \left| \frac{1}{j \omega C_{byp}} \right| \\
v_{RE1} &= i_e R_{E1} \quad \text{and} \quad v_{ZE2} = i_e Z_{E2}
\end{align*}
\]
Bypass for Gain - continued

Small signal circuit

\[ \beta = 100 \]

Desired circuit for \( f \geq f_{\text{min2}} \)

i.e. CONSERVATIVE DESIGN GOAL:
Choose \( C_{\text{byp}} \) s.t. \( |v_{\text{ZE2}}| << |v_{\text{RE1}}| \) for \( f \geq f_{\text{min2}} \)
Need to develop a design equation for $C_{byp}$

s.t. DESIGN GOAL: $|v_{ZE2}| << |v_{RE1}|$

where

$$Z_{E2} = \frac{R_{E2}}{j \omega C_{byp} R_{E2} + 1}$$

$$\left| \frac{v_{ZE2}}{V_{RE1}} \right| = \left| \frac{Z_{E2} i_e}{R_{E1} i_e} \right| = \left| \frac{R_{E2}/R_{E1}}{j \omega C_{byp} R_{E2} + 1} \right| \leq \frac{1}{10}$$

or

$$\left| j 2 \pi f_{min2} C_{byp} R_{E2} + 1 \right| \geq 10 \frac{R_{E2}}{R_{E1}} \gg 1$$

$$C_{byp} \geq 10 \frac{R_{E2}}{R_{E1}} \frac{1}{2 \pi f_{min2} R_{E2}} = \frac{10}{2 \pi f_{min2} R_{E1}}$$

$$C_{byp} = \frac{10}{2 \pi f_{min2} R_{E1}}$$

$i_e = (\beta + 1) i_b$

$\beta = 100$

$r_e \ll R_{E1}$

$v_{RE1} = i_e R_{E1} \quad \& \quad v_{ZE2} = i_e Z_{E2}$

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In Lab 2

Choose \( C_b \) s.t. \( \frac{1}{2\pi f_{\text{min1}} C_b} = R_{\text{in}} = R_B \parallel r_{bg} \approx R_B \)

\[ f_{\text{min1}} = 10 \text{Hz} \]

\[ C_b = \frac{1}{2\pi f_{\text{min1}} R_B} = \frac{1}{20\pi R_B} \]

Choose \( C_{\text{byp}} \) s.t. \( \frac{1}{2\pi f_{\text{min2}} C_{\text{byp}}} = \frac{R_E}{2} \)

\[ f_{\text{min2}} = 100 \text{Hz} \]

\[ C_{\text{byp}} = \frac{1}{2\pi f_{\text{min2}} R_E / 2} = \frac{1}{100\pi R_E} \]
\[ C_{byp} = \frac{10}{2\pi f_{\min} R_E} = \frac{10}{2\pi \times 20 \times 1000} \quad F = 79.6 \mu F \]

You may choose \( C_{byp} = 100 \mu F \)

**Final Design**
Gain Calculation in Passband

Simple gain calculation:

\[
i_b = \frac{v_s}{R_s + r_{\pi} + (\beta + 1) R_{E1}} \approx \frac{v_s}{(\beta + 1) R_{E1}}
\]

\[
v_{out} = -R_C i_c = -R_C \beta i_b
\]

\[
v_{out} = \frac{-\beta R_C}{(\beta + 1) R_{E1}} v_s
\]

\[
A_v = \frac{v_{out}}{v_s} \approx - \frac{R_C}{R_{E1}} = -4
\]
Multisim Simulation

20 Hz Gain

I kHz Gain
What if $R_E$ is Fully Bypassed?

$$A_v = \frac{v_{out}}{v_s} \approx \frac{R_C}{R_E} = \infty ?$$
What if $R_E$ is Fully Bypassed?

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

\[ v_{out} = -R_C i_c = -R_C \beta i_b \]

\[ v_{out} = \frac{-\beta R_C}{R_s + r_\pi} v_s \approx \frac{-\beta R_C}{r_\pi} v_s \]

\[ = \frac{-\beta R_C}{\beta/g_m} v_s = -g_m R_C v_s \]

\[ A_v = \frac{v_{out}}{v_s} \approx -g_m R_C = -160 \]

$I_C = 1 \text{ mA}$

$g_m = I_C/V_T = 0.04 \text{ S}$

$r_\pi = \beta/g_m = 2.5 \text{ k}\Omega$