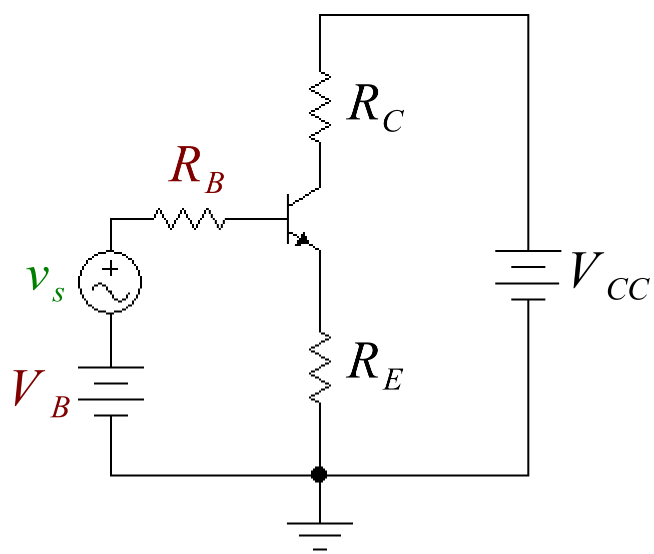
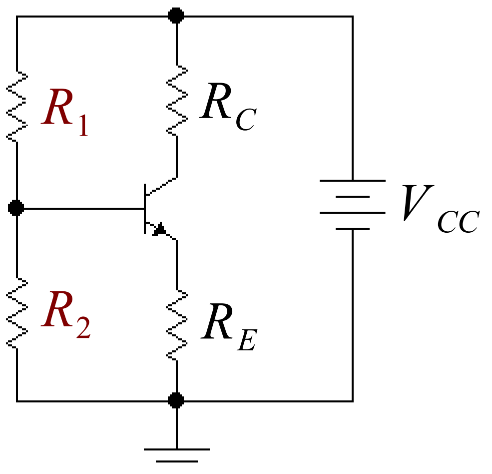
Common Emitter BJT Amplifier

Adding a signal source to the single power supply bias amplifier

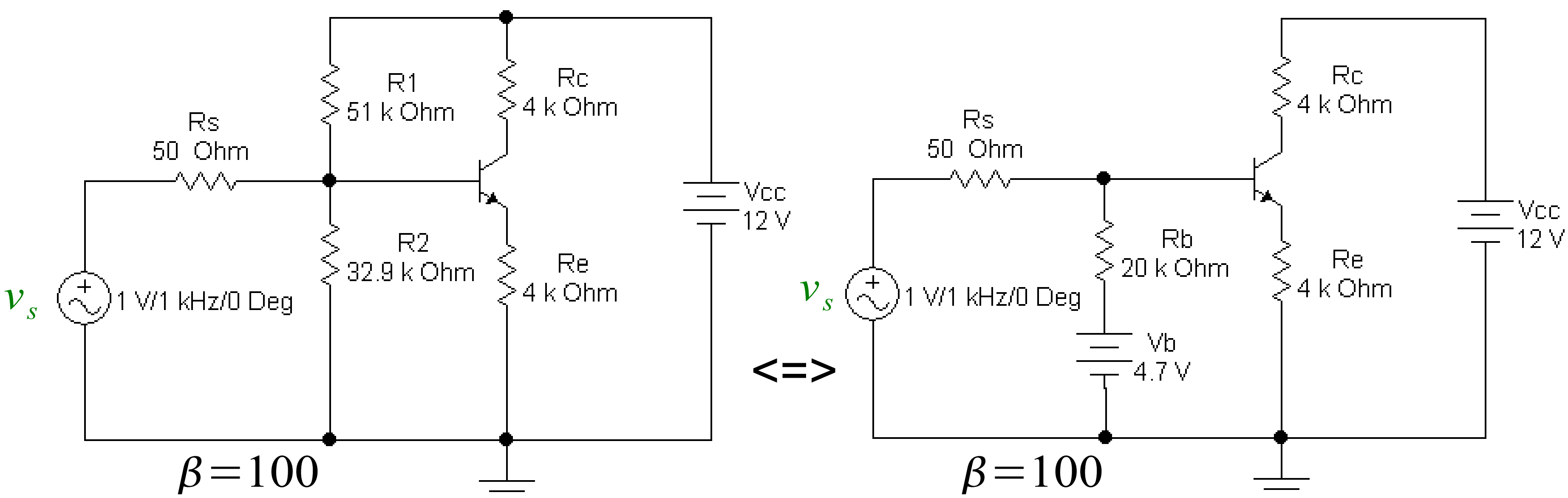


Desired effect – addition of bias and signal sources



Starting point - single dc source

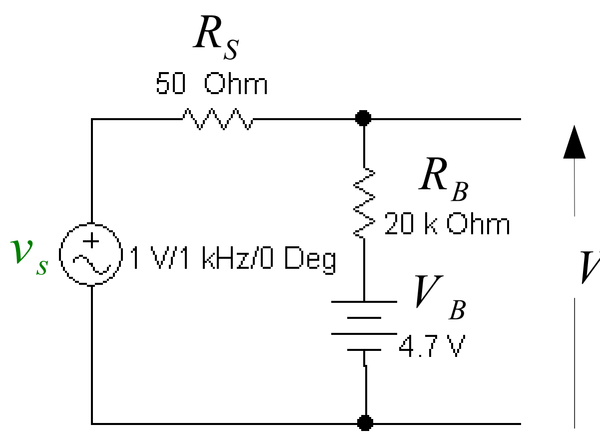
Wrong Way to Combine Sources



Source with low output impedance upsets bias.

Thevenin equivalent at base:

Wrong Way - Continued



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

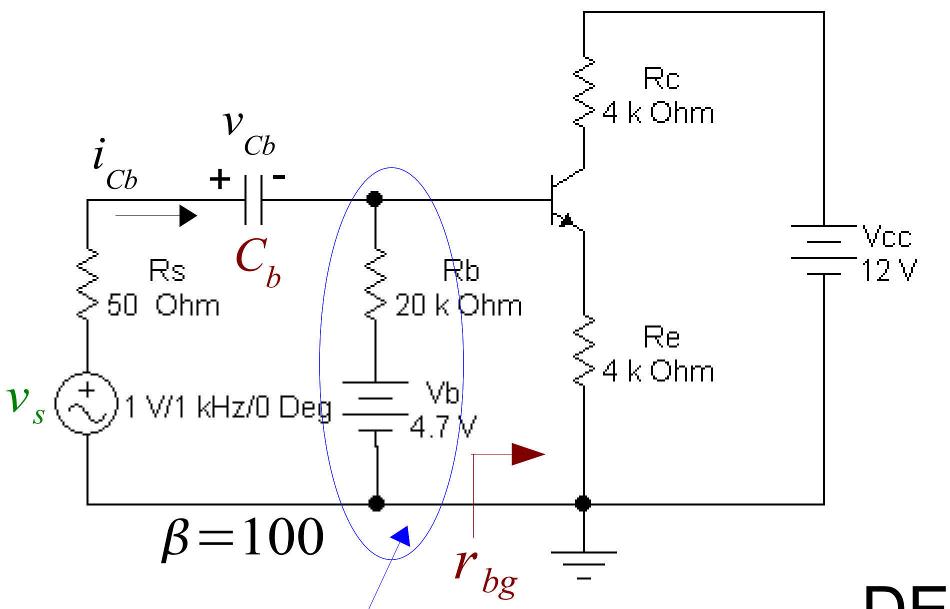
$$R_{th}=R_B'=R_B\|R_S=\frac{50\cdot 20000}{50+20000}\approx 50\,\Omega$$

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

The signal source effectively "shorts out" the bias source!

The signal source v_S is essentially is unaffected by the bias source V_B. (Why? What is its Thevenin equivalent?)

The Right Way – Use a "Blocking" Capacitor



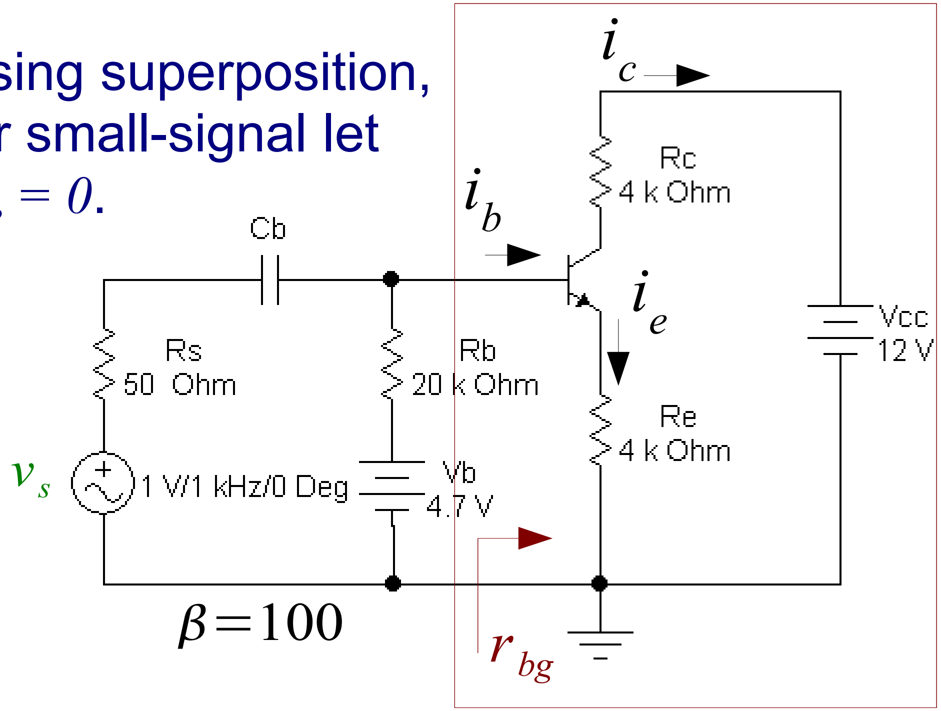
For convenience lets continue to use the "base bias Thevenin equiv".

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.* $v_S = V_B + v_s$

<u>DESIGN GOAL</u>: for $f \geq f_{min1}$, 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_{min1}.

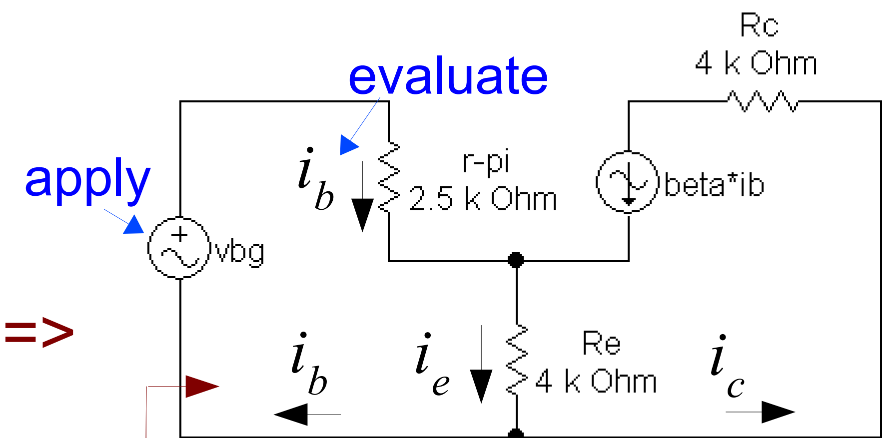
Blocking Capacitor Selection

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



$\beta = 100$

<=>



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

$$i_e = i_b + \beta i_b$$

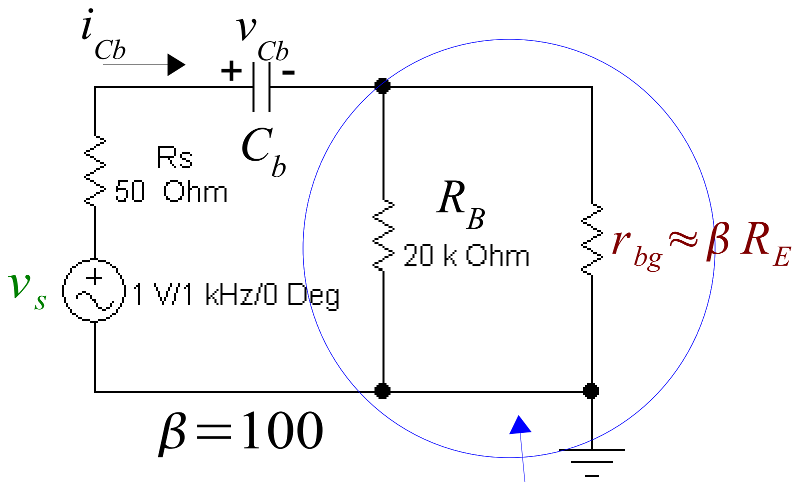
Use the small signal equivalent circuit and superposition to estimate the input resistance of the *transistor*.

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

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

Capacitor Selection- continued

The signal source "sees" the $20\ k\Omega$ bias source resistance in parallel with . So the signal source equivalent circuit is:



The capacitor voltage drop is:

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

Where the capacitor current is:

$$v_s = i_{Cb}\left(R_S + R_B \| r_{bg} + \frac{1}{j\omega C_b}\right)$$

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

Therefore:

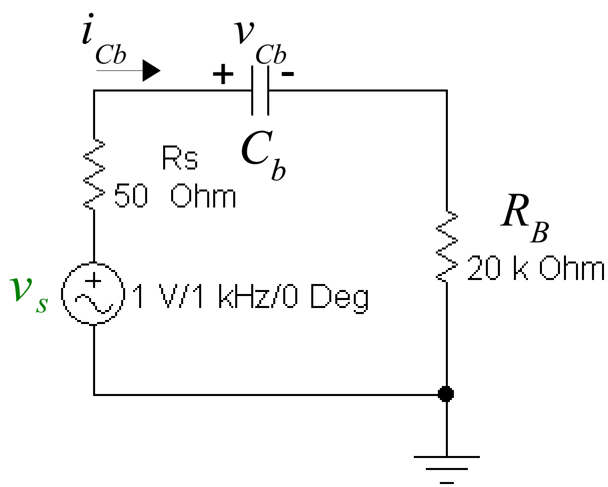
$$R_B \| r_{BG} = \frac{400}{420} 20 \approx 20\, k\,\Omega = R_B$$

$$i_{Cb} \approx \frac{v_s}{R_B + \frac{1}{j\omega C_b}} \Rightarrow v_{Cb} \approx \frac{v_s}{j\omega C_b R_B + 1}$$

Goal: $\omega C_b R_B \gg 1$

Capacitor Selection - continued

$$|v_{Cb}| \approx \frac{v_s}{|j\omega C_b R_B + 1|} \quad \text{or} \quad f_{R_B C_b} = \frac{1}{2\pi C_b R_B}$$



CONSERVATIVE DESIGN GOAL: Choose C_b for negligible voltage drop at v_{Cb} for $f \geq f_{min1}$, i.e.

$$|v_{Cb}| \approx \frac{v_s}{|j\omega C_b R_B + 1|} \leq \frac{v_s}{10} \quad \text{for } f \geq f_{min1}$$

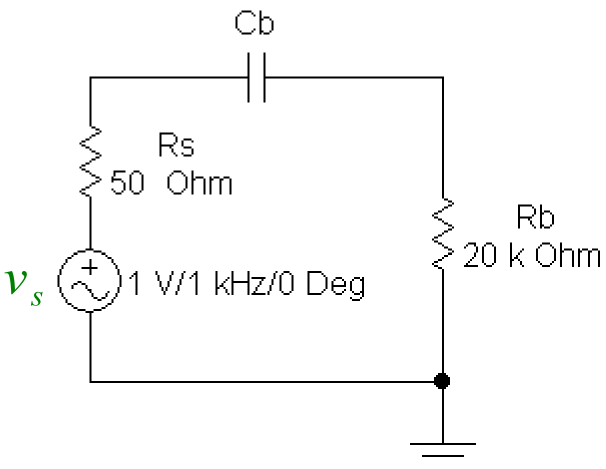
$$|v_{Cb}| \leq \frac{v_s}{10} \Rightarrow 2\pi f_{min1} C_b R_B \geq 10 \Rightarrow \boxed{C_b \geq \frac{10}{2\pi f_{min1} R_B}}$$

OR

DESIGN GOAL: Choose C_b so that $f_{R_B C_b} = 0.1 f_{min1}$, i.e.

$$f_{Cb} = \frac{1}{2\pi C_b R_B} = 0.1 f_{min1} \Rightarrow \boxed{C_b = \frac{10}{2\pi f_{min1} R_B}}$$

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:

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

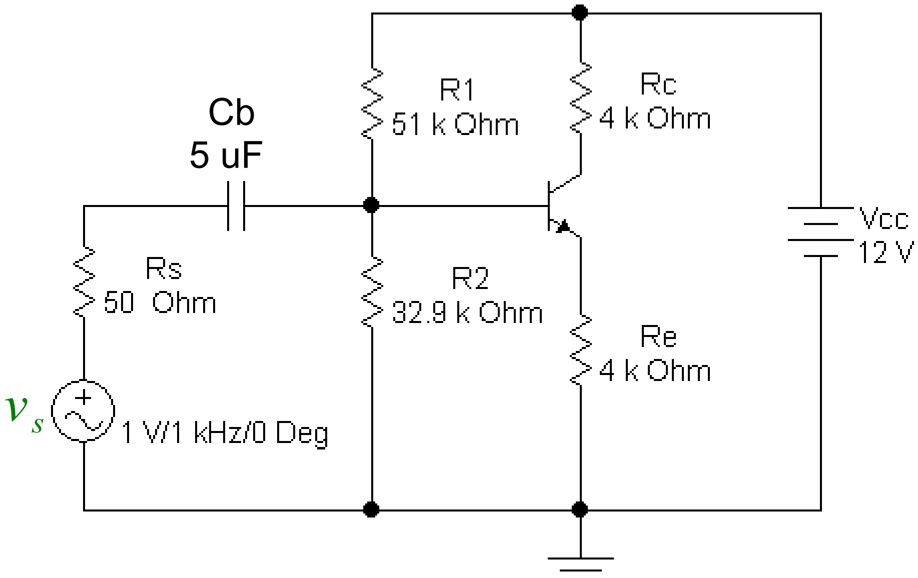
$$C_b \geq \frac{10}{2\pi f_{min1} R_B}$$

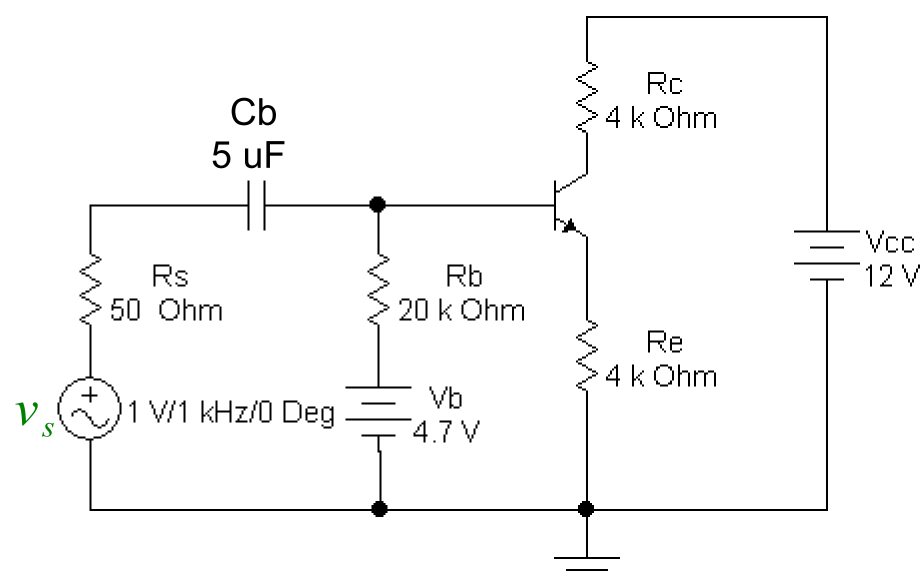
$$C_{b-min} = \frac{10}{125.6 \cdot 20 \cdot 10^3} = \frac{10^{-6}}{0.25} = 4\,\mu F$$

$$\boxed{C_{b-min} = \frac{10}{2\pi f_{min1} R_B}}$$

ANY capacitor larger than $4\,\mu F$ will also do the job!

Common Emitter Unity Gain Amplifier

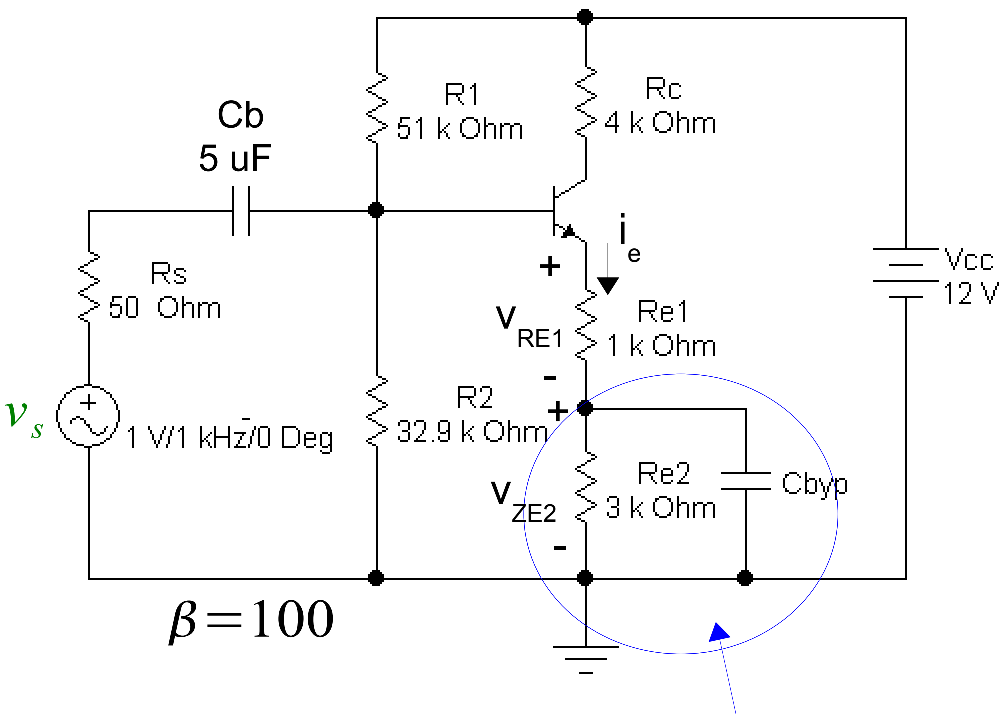




Equivalent circuits

How can we achieve reasonable gain with this circuit?
Solution: Split R_E and use *capacitor bypassing*.

Bypass for Gain



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

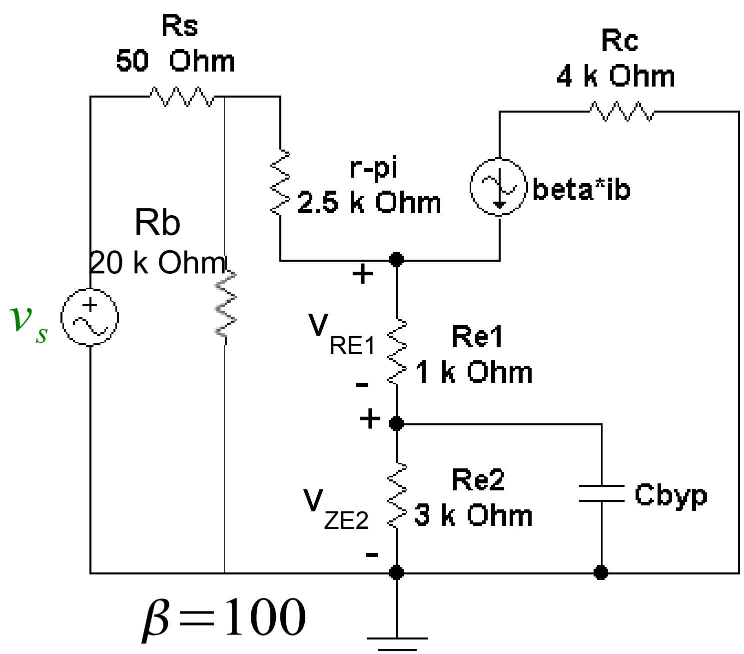
Procedure:

1. Split the emitter resistor in two. Later, we will show that the voltage gain will be close to $-R_C/R_{E1}$.
2. Bypass R_{E2} with a capacitor C_{byp} that looks like a near "short circuit" at some suitable low frequency $(f_{min2} \geq f_{min1})$.

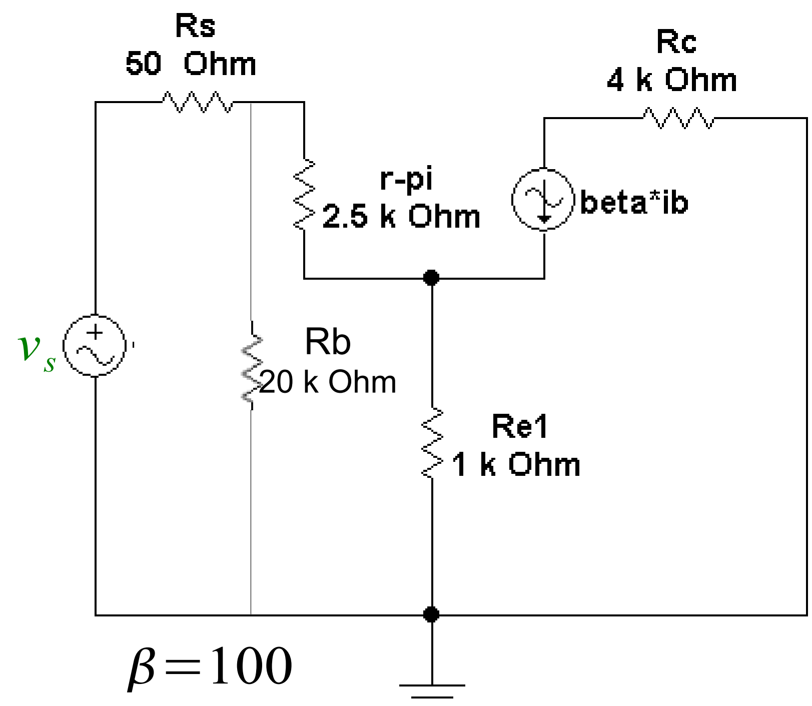
i.e. $|v_{ZE2}| << |v_{RE1}|$ for $f \geq f_{min2})$

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

Bypass for Gain - continued



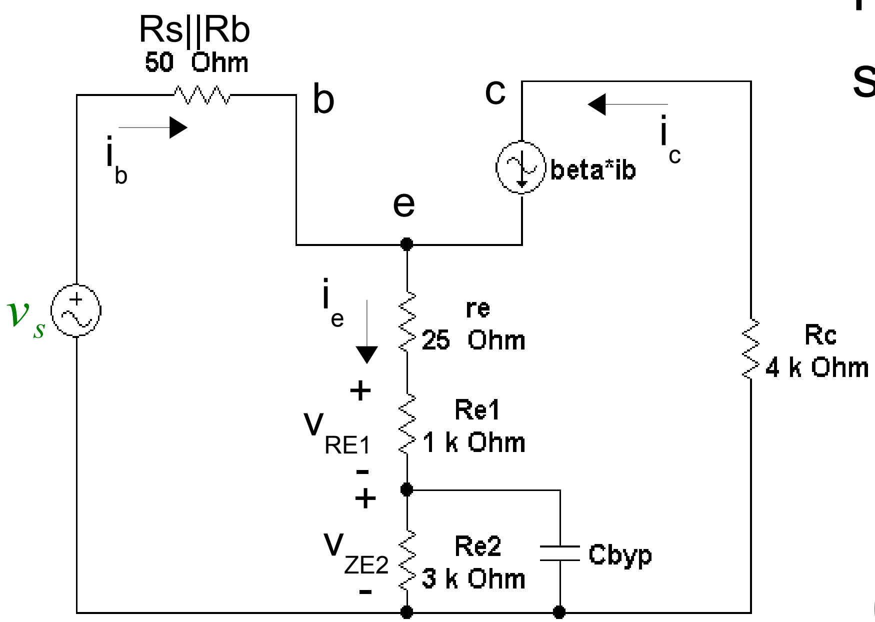
Small signal circuit



Desired circuit for $f \geq f_{min2}$

i.e. CONSERVATIVE DESIGN GOAL:
Choose C_{byp} s.t. $|v_{ZE2}| << |v_{RE1}|$ for $f \geq f_{min2}$

Need to develop a design equation for C_{byp}
s.t. DESIGN GOAL: $|v_{ZE2}| << |v_{RE1}|$



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

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

or

$$|j2\pi f_{min2}C_{byp}R_{E2}+1|\ge 10\frac{R_{E2}}{R_{E1}}\gg 1$$

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

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

$$i_e=(\beta+1)i_b$$

$$\beta=100$$

$$r_e\ll R_{E1}$$

$$v_{RE1}=i_eR_{E1}\ \&\ \ v_{ZE2}=i_eZ_{E2}$$

In Lab 2

$$C_b = \frac{10}{2\pi f_{min1} R_B}$$

Choose C_b $s.t.$ $\frac{1}{2\pi f_{min1} C_b} = R_{in} = R_B \| r_{bg} \approx R_B$

$$f_{min1} = 10\text{Hz}$$

$$C_b = \frac{1}{2\pi f_{min1} R_B} = \frac{1}{20\pi R_B}$$

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

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

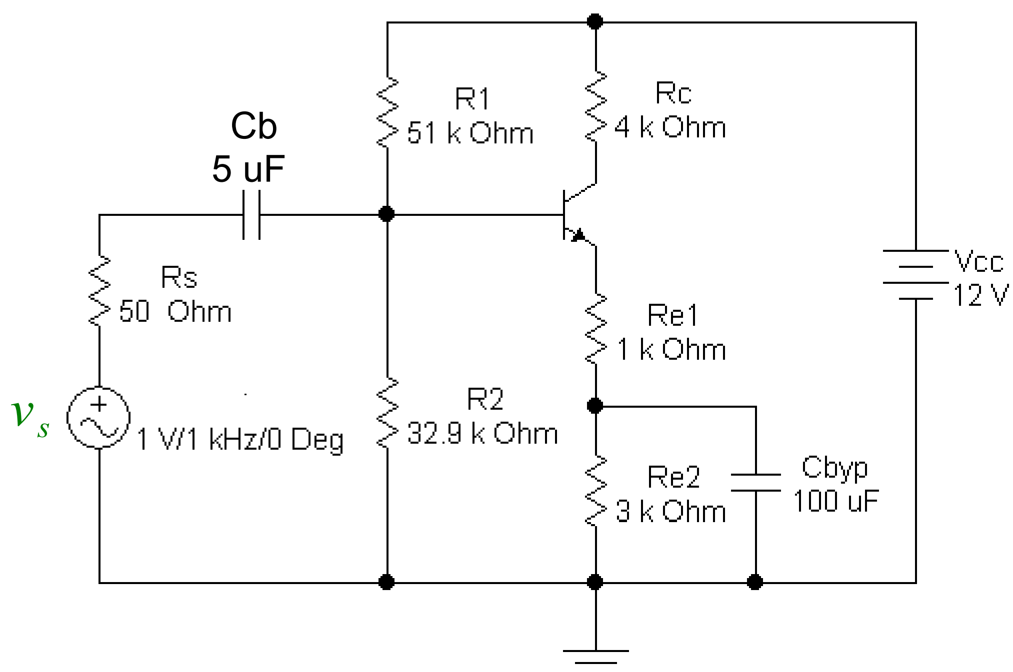
$$f_{min2} = 100\text{Hz}$$

$$C_{byp} = \frac{1}{2\pi f_{min2} R_E/2} = \frac{1}{100\pi R_E}$$

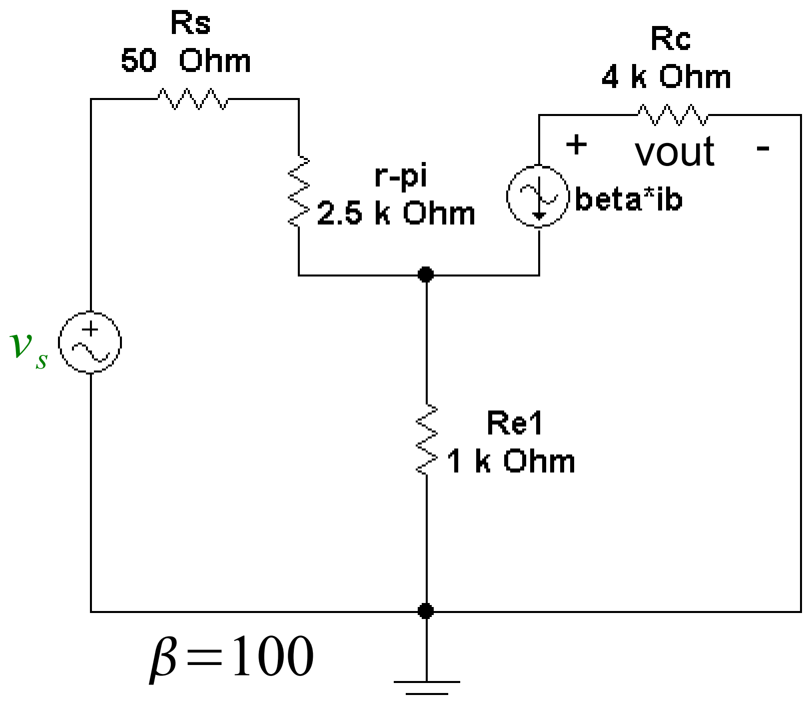
$$C_{byp} = \frac{10}{2\pi f_{min} R_{E1}} = \frac{10}{2\pi x 20 x 1000} F = 79.6\mu F$$

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

Final Design



Gain Calculation in Passband



$\beta = 100$

Passband model

Simple gain calculation:

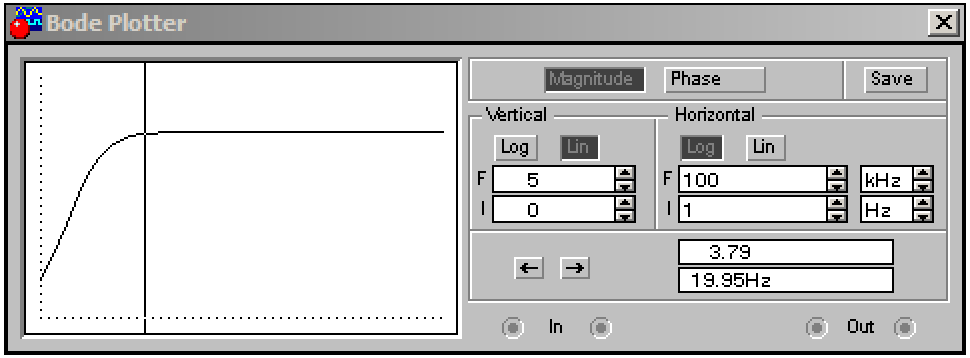
$$i_b = \frac{v_s}{R_s + r_\pi + (\beta+1) R_{E1}} \approx \frac{v_s}{(\beta+1) R_{E1}}$$

$$v_{out} = -R_C i_c = -R_C \beta i_b$$

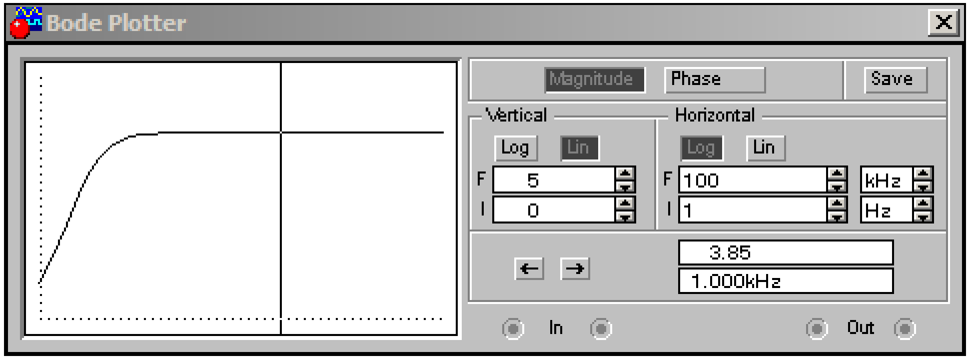
$$v_{out} = \frac{-\beta R_C}{(\beta+1) R_{E1}} v_s$$

$$A_v = \frac{v_{out}}{v_s} \approx -\frac{R_C}{R_{E1}} = -4$$

Multisim Simulation



20 Hz Gain



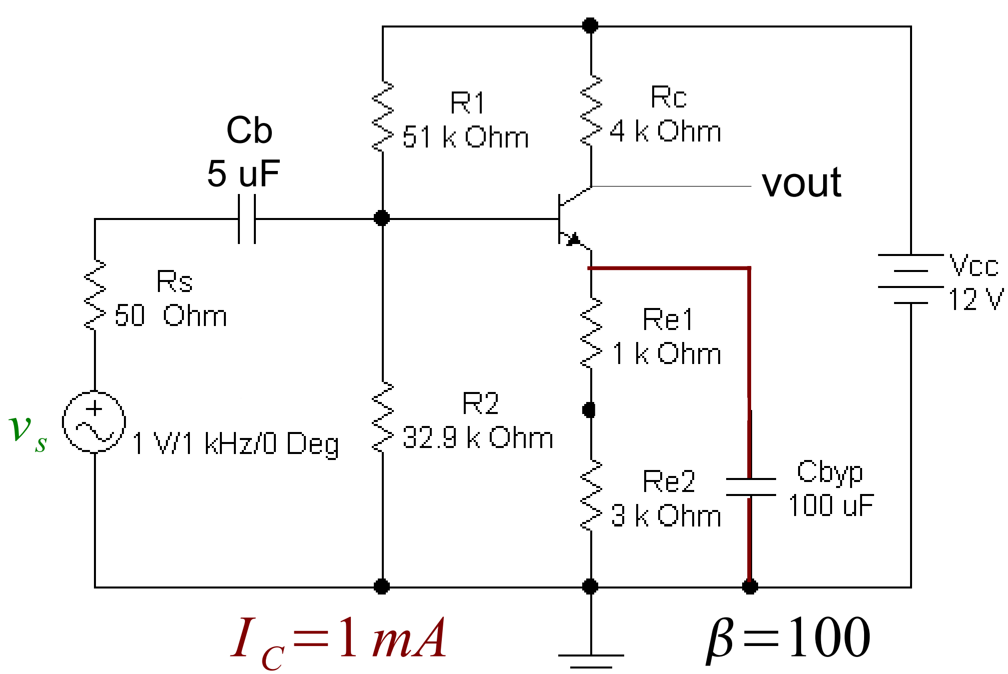
I kHz Gain

What if R_E is Fully Bypassed?

$$A_v = \frac{v_{out}}{v_s} \approx -\frac{R_C}{R_E} = \infty \ ?$$

$R_E \rightarrow 0$

What if R_E is Fully Bypassed?



$$I_C = 1\,mA \qquad \beta = 100$$

$$g_m = I_C / V_T = 0.04\,S$$

$$r_\pi = \beta / g_m = 2.5\,k\,\Omega$$

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

($R_E \to 0$)

$$v_{out} = -R_C i_c = -R_C \beta i_b$$

$$v_{out} = \frac{-\beta R_C}{R_S + r_\pi} v_s \approx \frac{-\beta R_C}{r_\pi} v_s$$

$$. = \frac{-\beta R_C}{\beta / g_m} v_s = -g_m R_C v_s$$

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