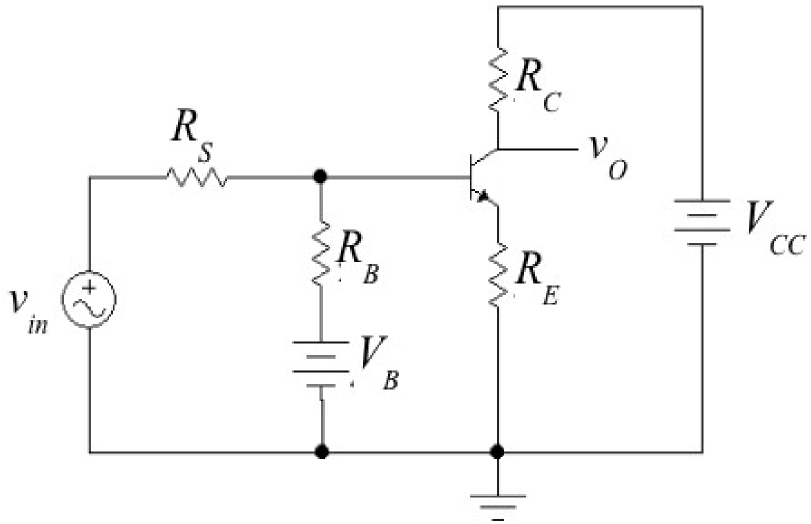
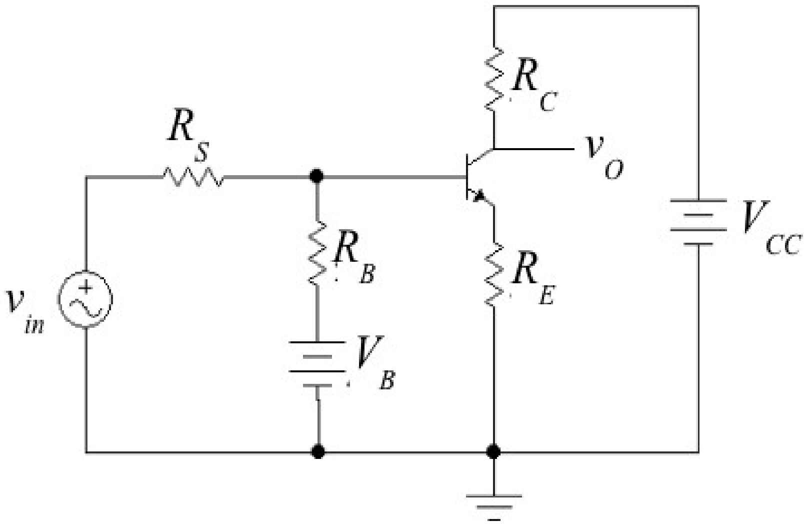
Quick Review



What, if anything, is wrong with this amplifier design?

If there is something(s) wrong, how can it (they) be remedied?

Quick Review



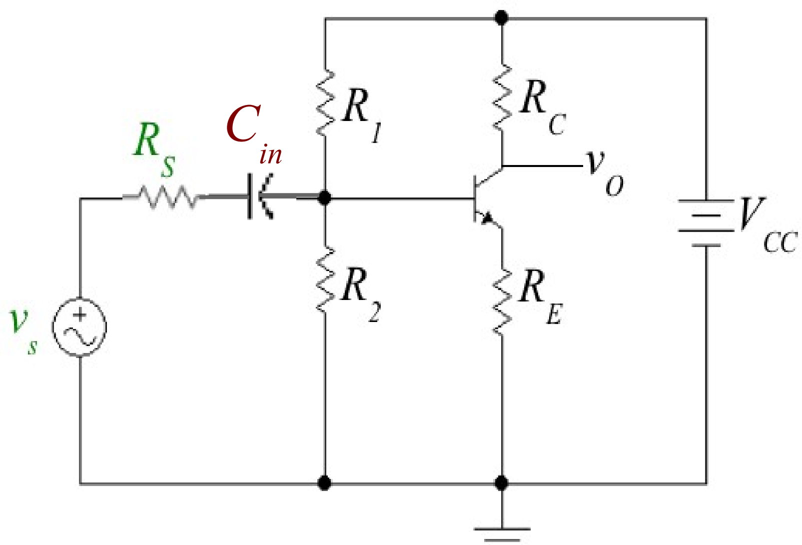
What, if anything, is wrong with this amplifier design?

1. V_B is effectively shorted out by v_{in}.
2. DC on v_{in} corrupts the op. pt. (i.e. V_C & I_C).
3. The voltage gain is - R_C/R_E.

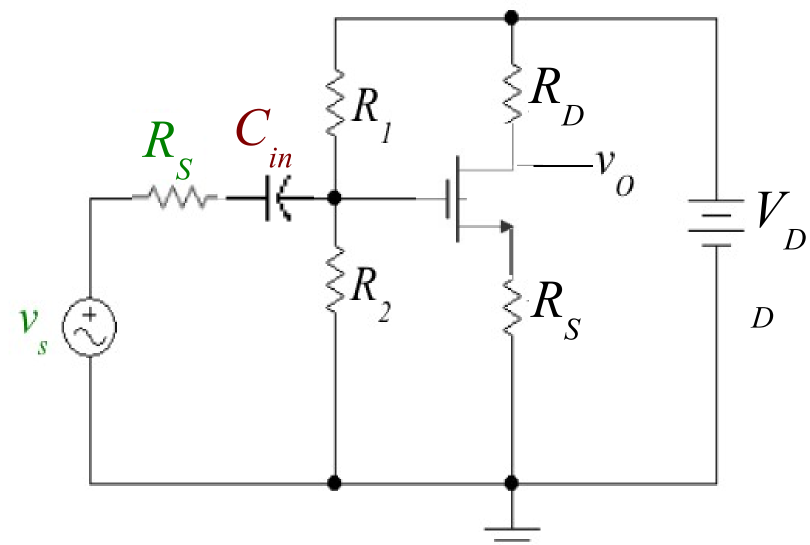
If there is something(s) wrong, how can it (they) be remedied?

1. Insert blocking capacitor C_{in} in series with R_S.
2. Insert bypass capacitor C_{byp} in parallel with all or part of R_E.

Common Emitter (CE) BJT Amplifier

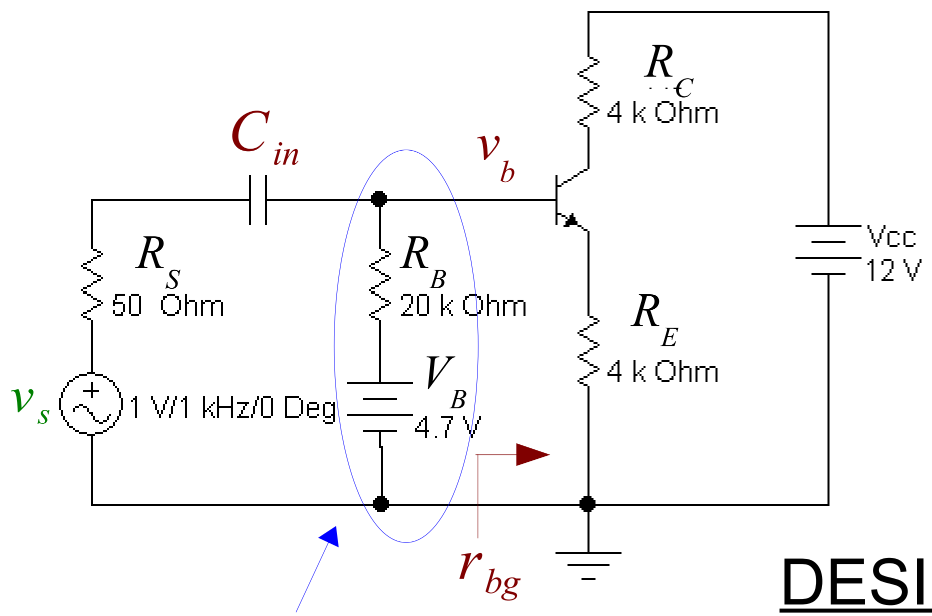


CE BJT Amplifier



CS MOS Amplifier

The Right Way – Use a "Blocking" Capacitor



1. Capacitor C_{in} is an OPEN at dc and v_s, R_S do not affect the bias!

2. Capacitor C_{in} is a SHORT at some $f \geq f_{min}$ and $v_B \approx V_B + v_s$

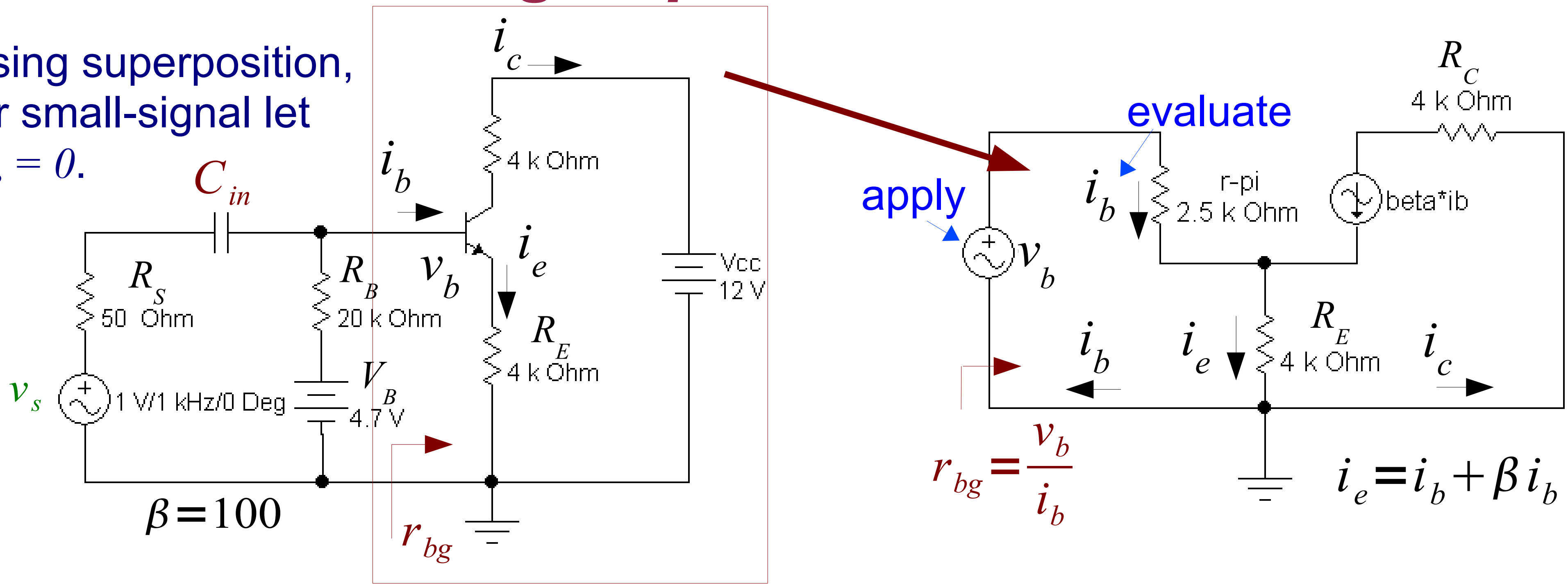
For convenience lets continue to use the "base bias Thevenin equiv".

DESIGN GOAL: for $f \geq f_{min}$, set the value of C_{in} s.t the ac base voltage

$$v_b \approx v_s$$

Blocking Capacitor Selection

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



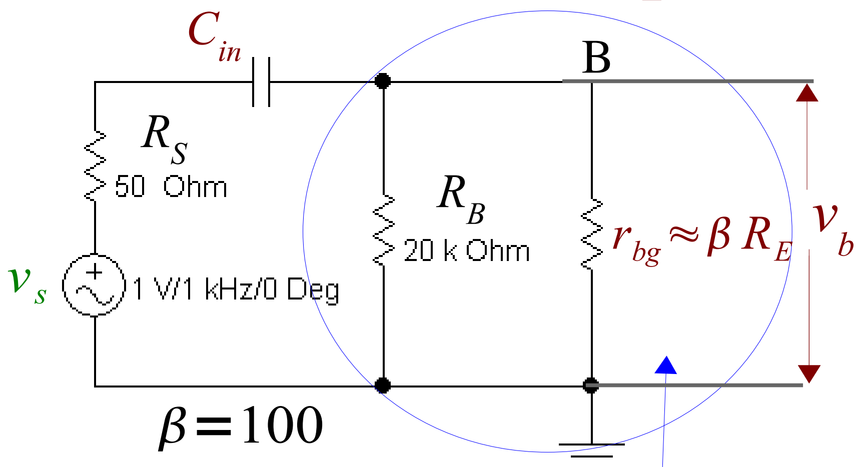
Use the small signal equivalent circuit and superposition to estimate the input resistance of the *transistor*.

$$v_b = i_b r_\pi + i_e R_E = i_b r_\pi + i_b (\beta + 1) R_E$$

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

Capacitor Selection- continued

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



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

Therefore:

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

Using the voltage-divider relation:

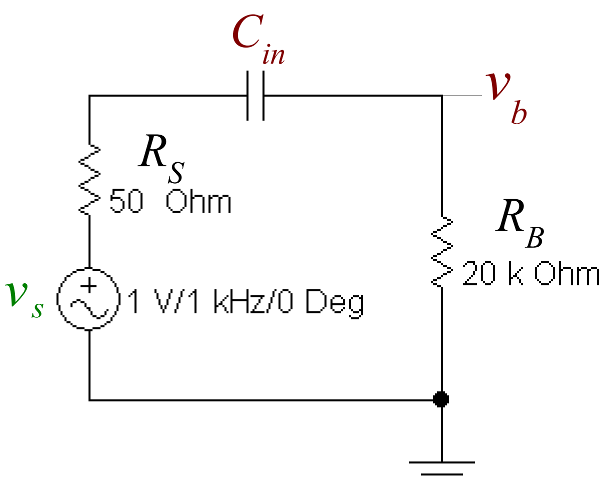
$$v_b = \frac{R_B \| r_{bg}\, v_s}{R_B \| r_{bg} + R_S + \frac{1}{j\omega C_{in}}} \approx \frac{R_B\, v_s}{R_B + \frac{1}{j\omega C_{in}}}$$

Design objective: for a known R_B, determine C_{in} s.t. $v_b \approx v_s$

i.e. $R_B \gg \left|\frac{1}{j\omega C_{in}}\right|$ => $2\pi f C_{in} R_B \gg 1$

Capacitor Selection - continued

$$2\pi f C_{in} R_B \gg 1 \quad \Rightarrow \quad C_{in} \gg \frac{1}{2\pi f R_B}$$



FACTOR-OF-10 DESIGN GOAL: Choose C_{in} s.t. for a specified min frequency $f = f_{min}$

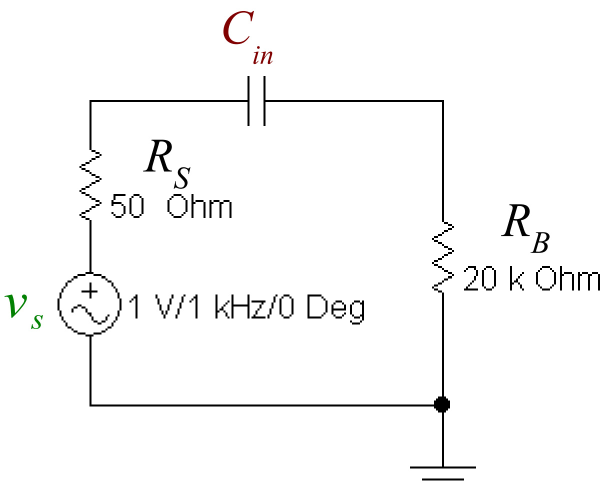
$$C_{in} = \frac{10}{2\pi f_{min} R_B}$$

Hence

$$v_b \approx \frac{R_B v_s}{R_B + \dfrac{1}{j2\pi f C_{in}}} = \frac{R_B v_s}{R_B + \dfrac{R_B}{10}\dfrac{f_{min}}{f}} = \frac{v_s}{1 + \dfrac{1}{10}\dfrac{f_{min}}{f}} \approx v_s$$

for $f = f_{min}$ $\quad v_b \approx \dfrac{v_s}{1 + \dfrac{1}{10}} = 0.91\, v_s$ & for $f = 10 f_{min}$ $\quad v_b \approx \dfrac{v_s}{1 + \dfrac{1}{100}} = 0.99\, v_s$

Capacitor Selection - continued



$$C_{in} = \frac{10}{2\pi f_{min} R_B}$$

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

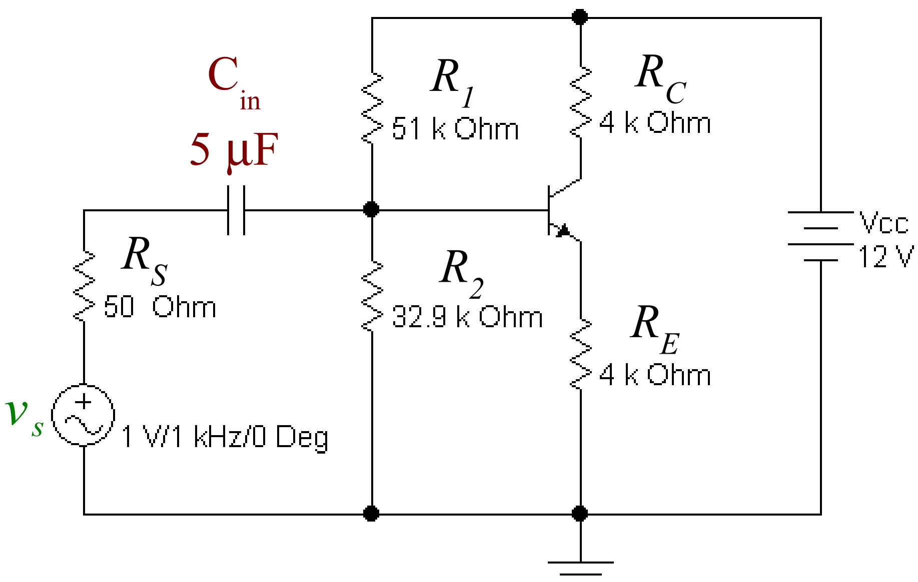
$$2\pi f_{min} = 2\pi 20 \approx 6.28 \cdot 20 = 125.6\, sec^{-1}$$

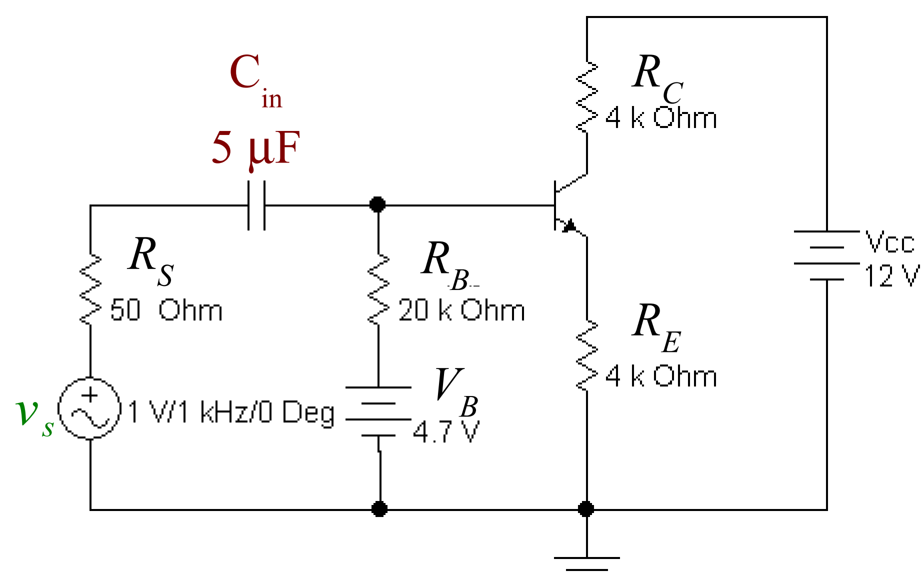
$$C_{in} = \frac{10}{125.6 \cdot 20 \cdot 10^3} = \frac{10^{-6}}{0.25} = 4\,\mu F$$

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

Let's choose $C_{in} = 5\ \mu F$

Common Emitter Unity Gain Amplifier

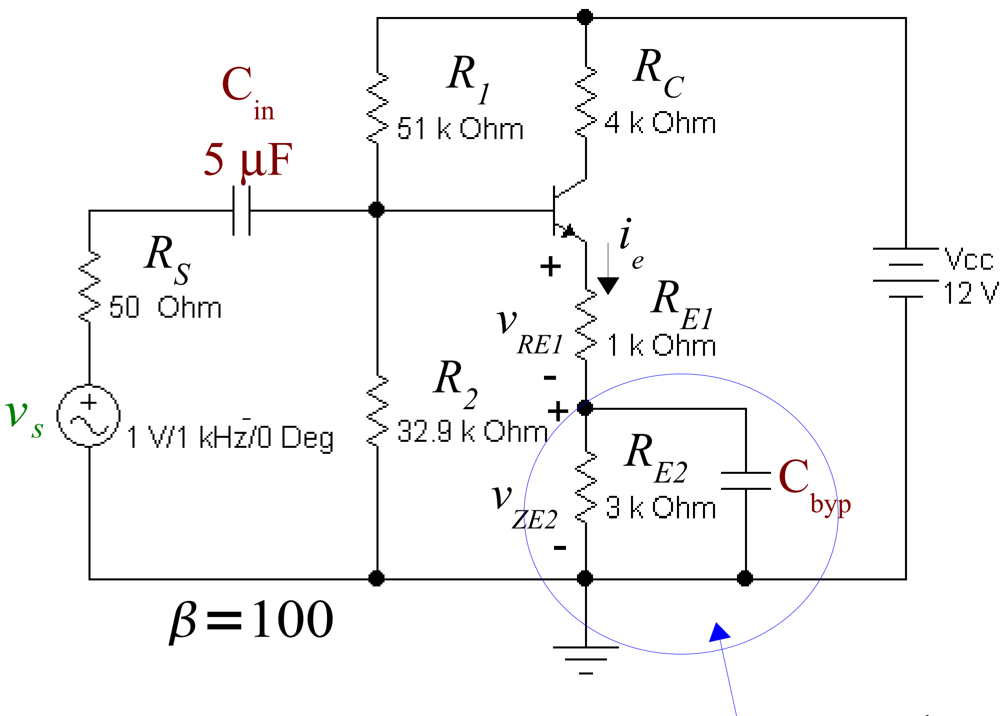




Equivalent circuits

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

Bypass for Gain



Procedure:

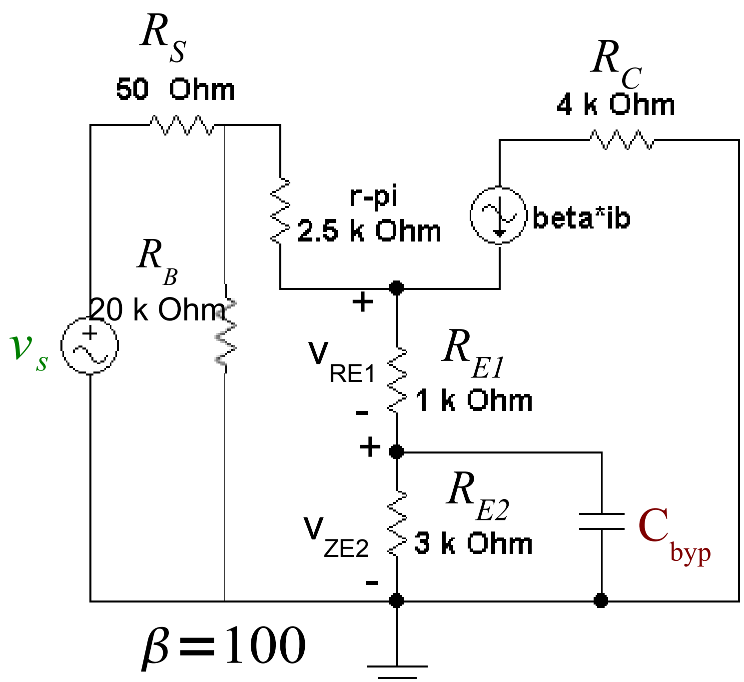
1. Split the emitter resistor in two. Later, we will show that the voltage gain will be close to $-R_C/R_{E1}$.
2. Bypass R_{E2} with a capacitor C_{byp} that looks like a near "short circuit" at some suitable low frequency $(f = f_{min})$.

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

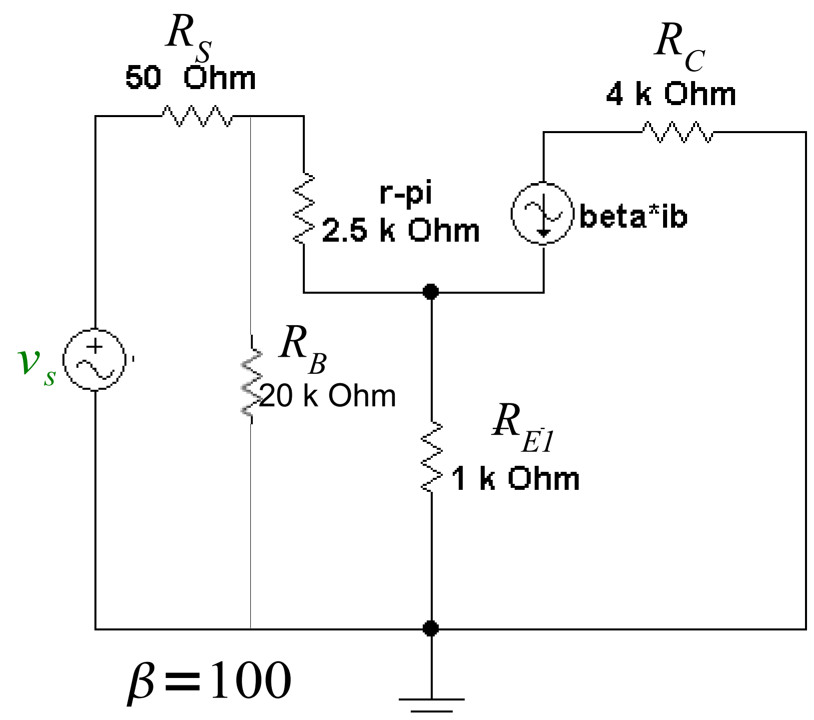
$$Z_{E2} = R_{E2} \| \frac{1}{j 2 \pi f C_{byp}}$$

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

Bypass for Gain - continued

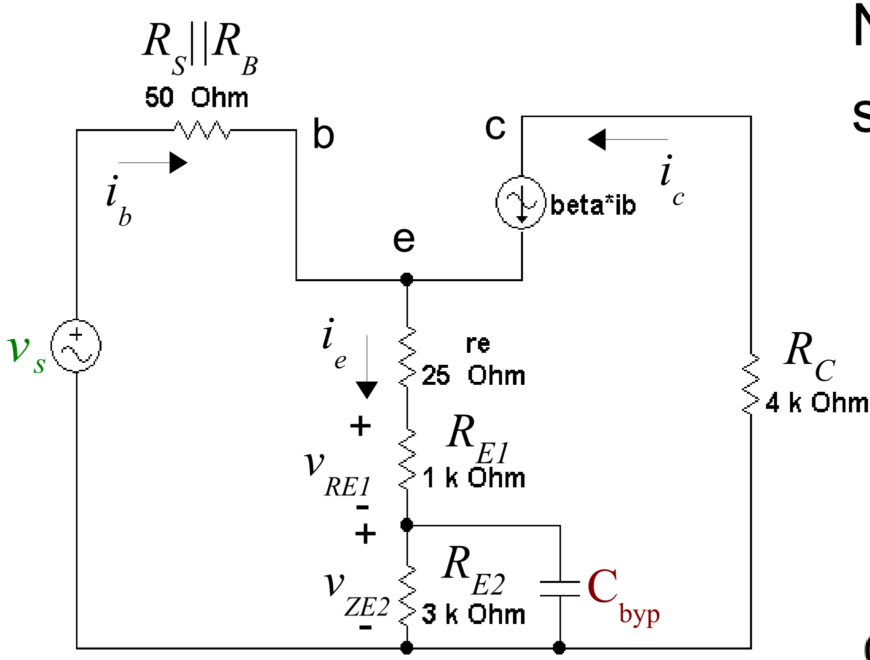


Small signal circuit



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

i.e. CONSERVATIVE DESIGN GOAL:
Choose C_{byp} s.t. $|v_{ZE2}| = 0.1 \ |v_{RE1}|$ for $f \geq f_{min}$



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

$$\beta=100$$

$$r_e \ll R_{E1}$$

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

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

where

$$Z_{E2}=R_{E2}\|\frac{1}{j2\pi C_{byp}}=\frac{R_{E2}}{j2\pi f C_{byp} R_{E2}+1}$$

$$\left|\frac{v_{ZE2}}{v_{RE1}}\right|=\left|\frac{Z_{E2} i_e}{R_{E1} i_e}\right|=\left|\frac{R_{E2}/R_{E1}}{j2\pi f_{min} C_{byp} R_{E2}+1}\right|=\frac{1}{10}$$

or

Solving for C_{byp}:

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

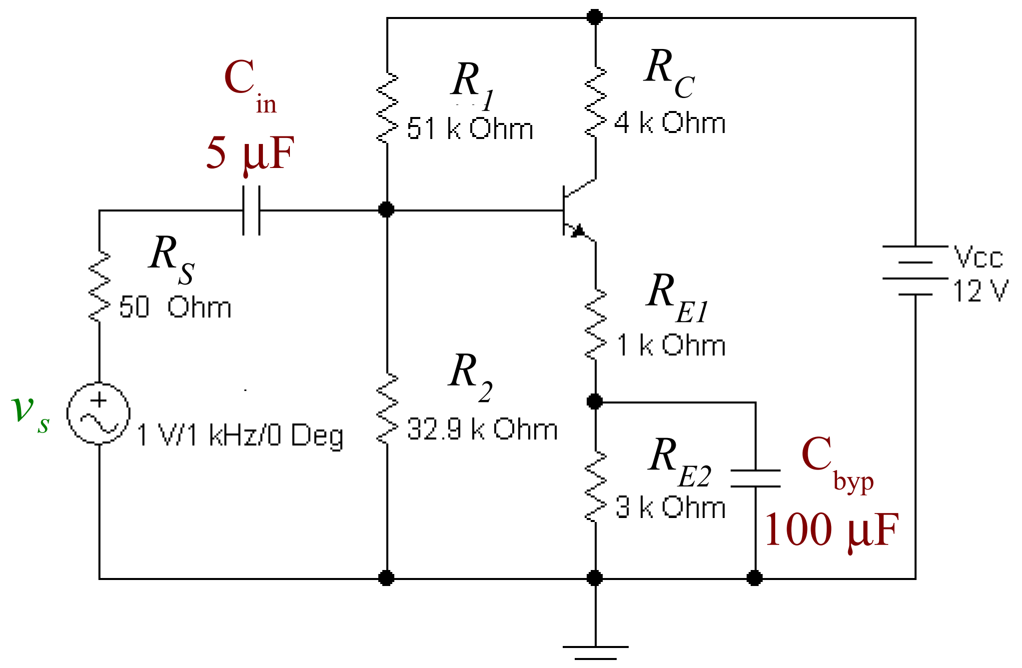
$$\boxed{C_{byp}=\frac{10}{2\pi f_{min} R_{E1}}}$$

a larger value C_{byp} also works

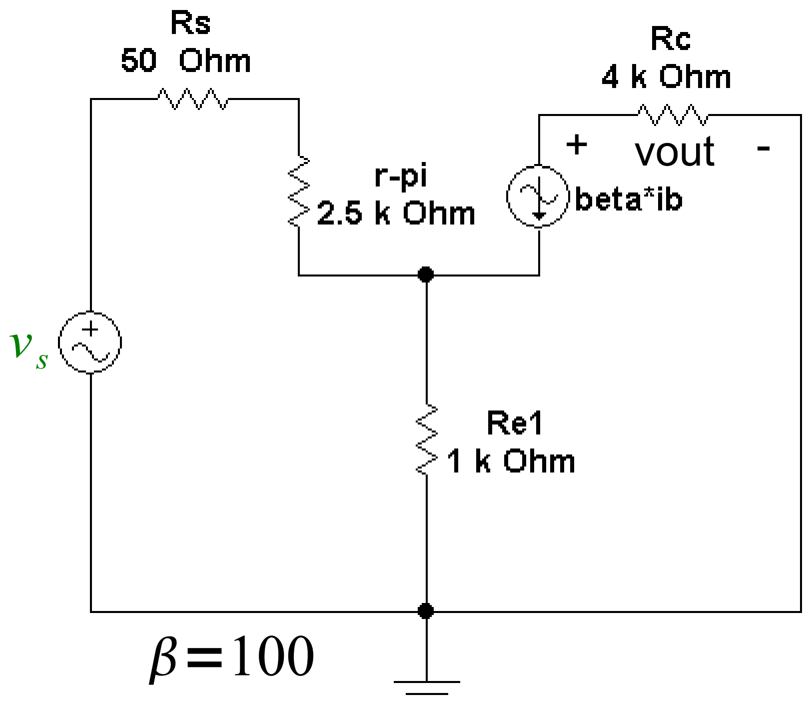
$$C_{byp} = \frac{10}{2\pi f_{min} R_{E1}} = \frac{10}{2\pi x\, 20\, x\, 1000} F = 79.6\,\mu F$$

Let's choose $C_{byp} = 100\ \mu F$

Final Design



Gain Calculation in Passband



$\beta = 100$

mid-band model

Simple gain calculation:

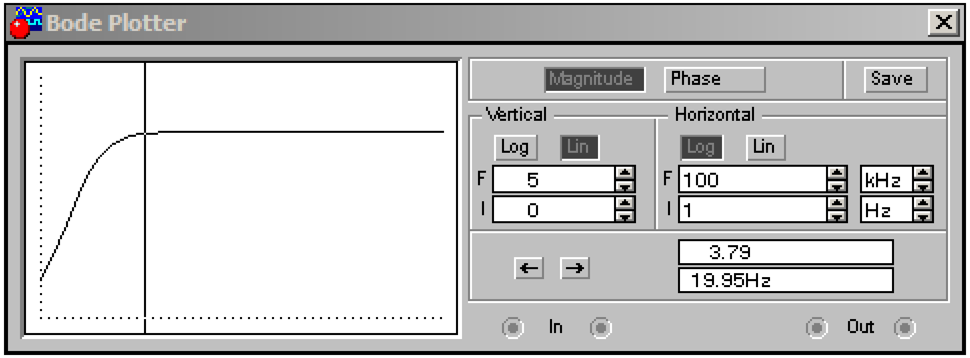
$$i_b = \frac{v_s}{R_s + r_\pi + (\beta+1) R_{E1}} \approx \frac{v_s}{(\beta+1) R_{E1}}$$

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

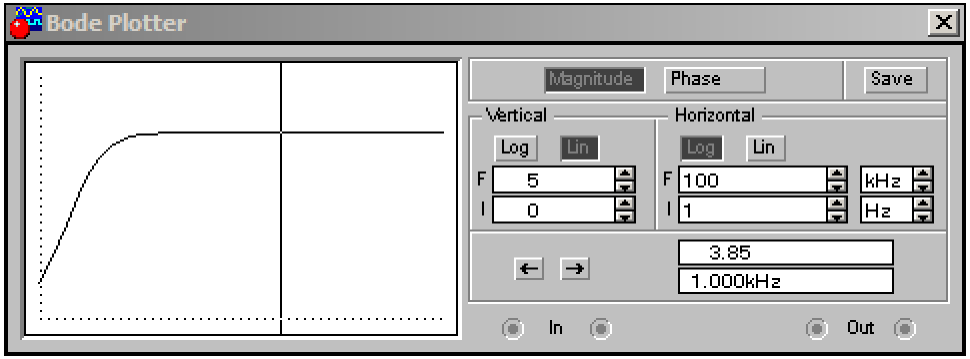
$$v_{out} = \frac{-\beta R_C}{(\beta+1) R_{E1}} v_s$$

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

Multisim Simulation



20 Hz Gain



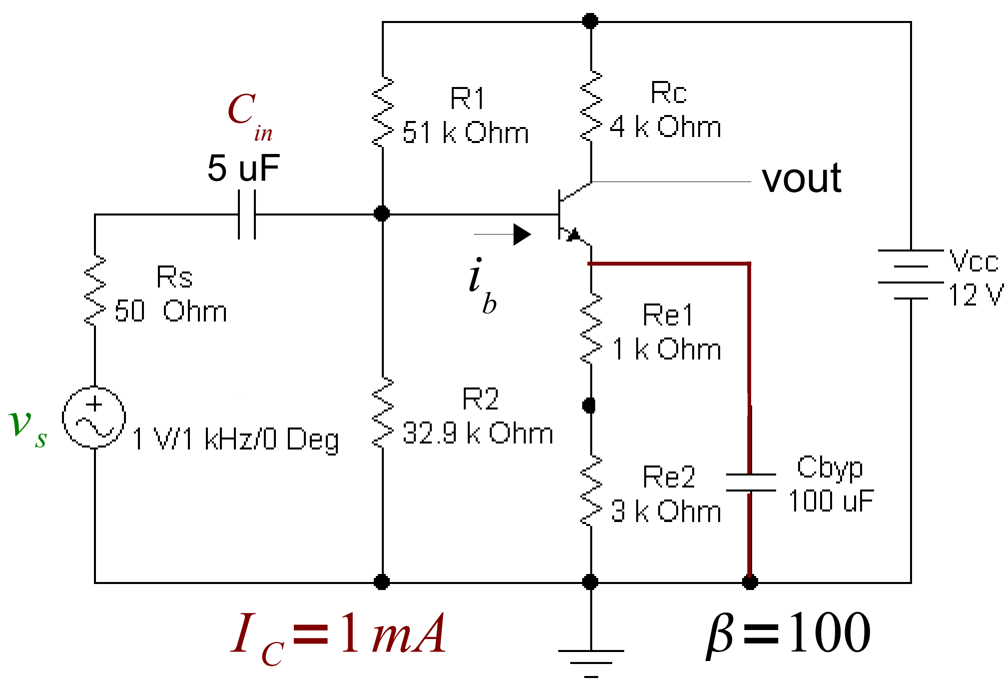
I kHz Gain

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?



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

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

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

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

($R_E \to 0$)

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

where $i_b = \dfrac{v_b}{r_\pi} \approx \dfrac{v_s}{r_\pi}$

$$v_{out} \approx \frac{-\beta R_C}{r_\pi} v_s = \frac{-\beta R_C}{\beta / g_m} v_s = -g_m R_C v_s$$

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