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

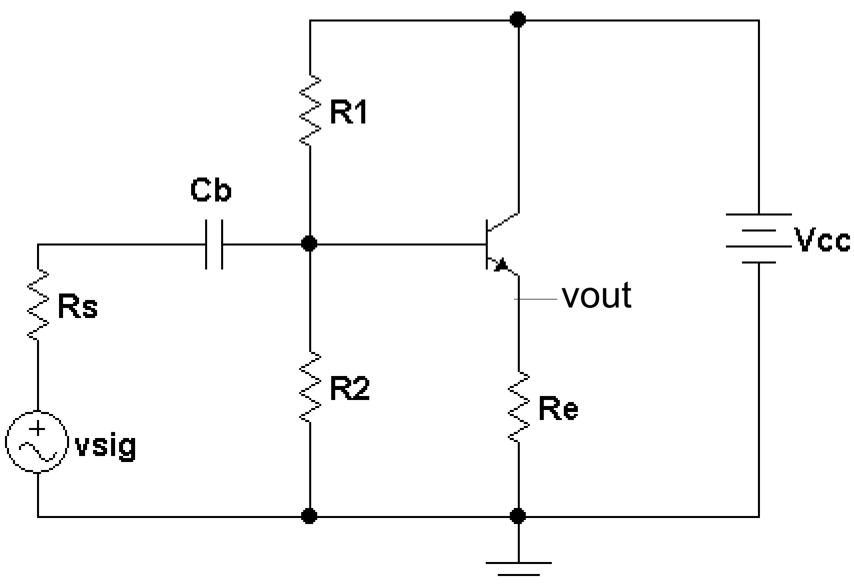
	CE Amplifier	CC Amplifier	CB Amplifier
Voltage Gain (A_V)	moderate ($-R_C/R_E$)	low (about 1)	high
Current Gain (A_I)	moderate (β)	moderate ($\beta+1$)	low (about 1)
Input Resistance	high	high	low
Output Resistance	high	low	high

CE BJT amplifier => CS MOS amplifier

CC BJT amplifier => CD MOS amplifier

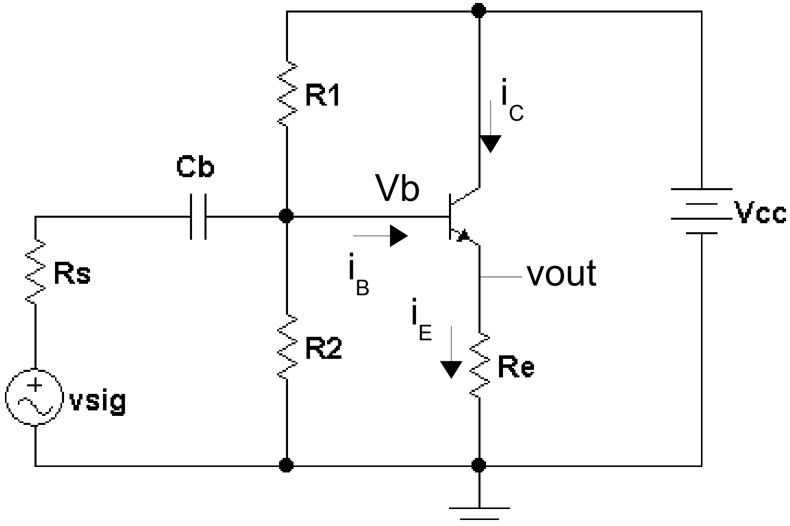
CB BJT amplifier => CG MOS amplifier

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:

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

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

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

$$\boxed{R_1 = R_2 = 20\, R_E}$$

Typical Design

Choose: $I_E = 1\, mA$

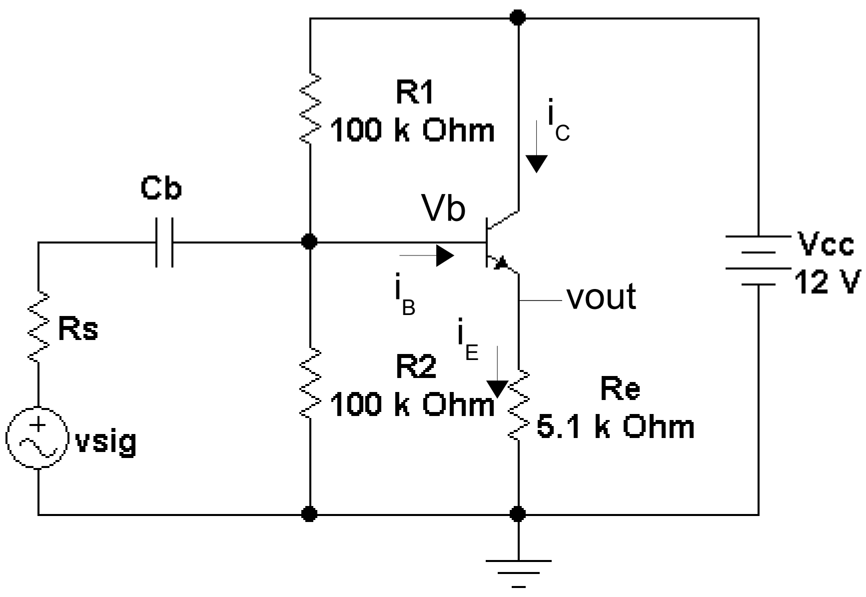
$V_{CC} = 12\, V$

And the rest of the design follows immediately:

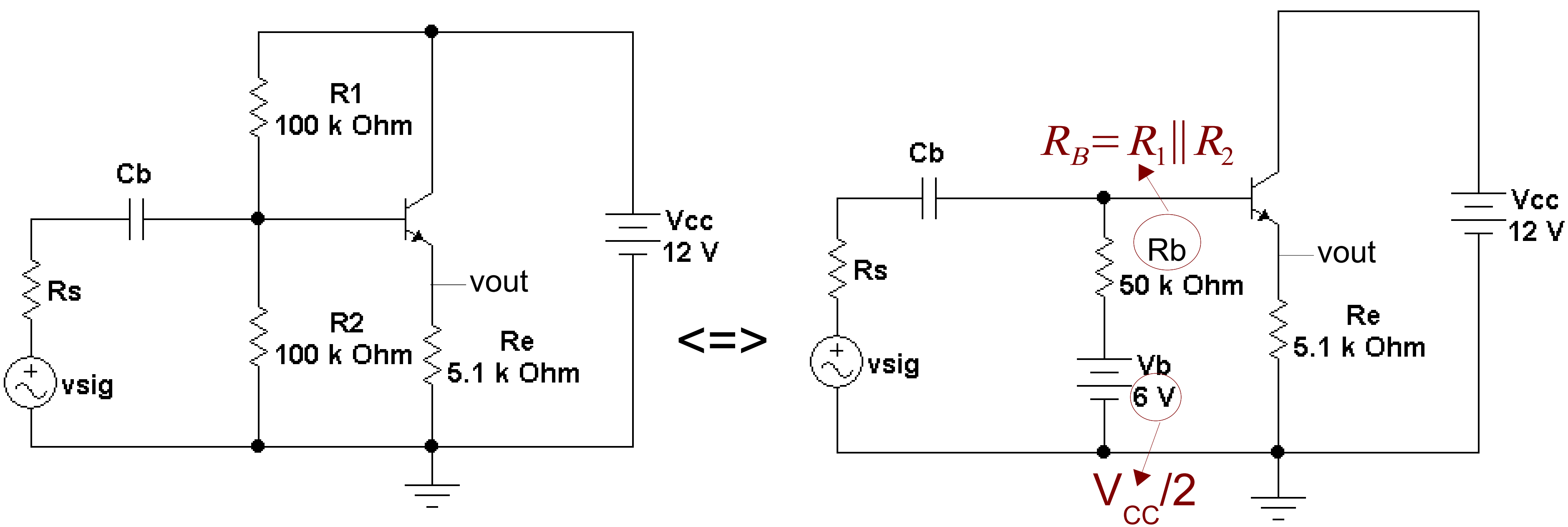
$$R_E = \frac{V_E}{I_E} = \frac{12/2 - 0.7}{10^{-3}} = 5.3\, k\Omega$$

Use standard sizes

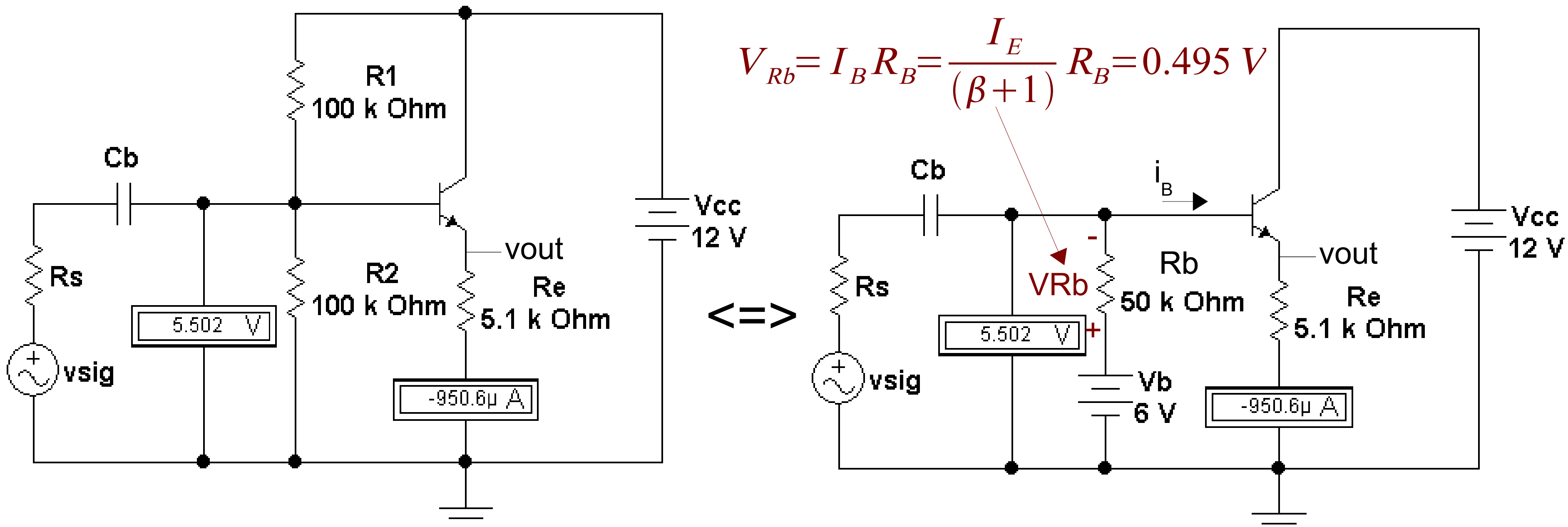
$$\boxed{\begin{gathered} R_E = 5.1\, k\Omega \\ R_1 = R_2 = 100\, k\Omega \end{gathered}}$$



Equivalent Circuits



Multisim Bias Check



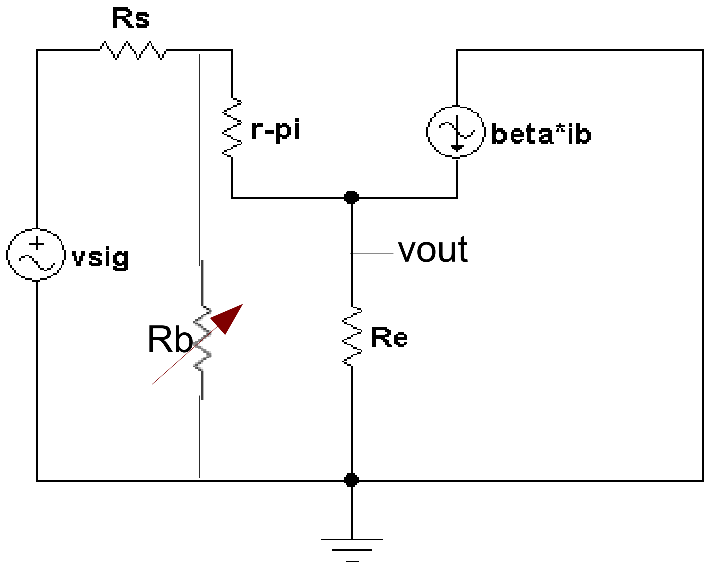
Identical results – as expected!

Emitter Follower Small Signal Circuit

Mid-band equivalent circuit:

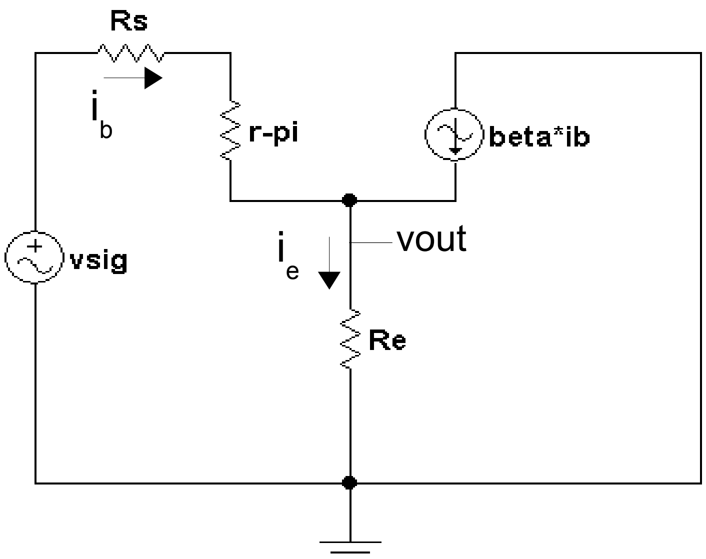
$$v_{sig}' = \frac{R_B}{R_B + R_S} v_{sig} = \frac{50}{50.05} v_{sig} \approx v_{sig}$$

$$R_{TH} = R_S \| R_B = \frac{50}{50.05} R_S \approx R_S$$



Small signal mid-band circuit - where C_B has negligible reactance (above ω_{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:

$$v_{sig} = (R_S + r_\pi + (\beta+1) R_E) i_b$$

Solving for i_b

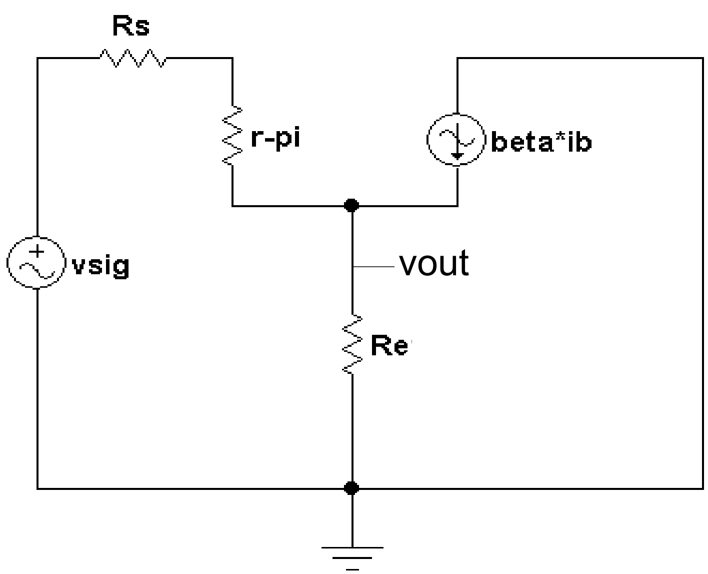
$$i_b = \frac{v_{sig}}{R_S + r_\pi + (\beta+1) R_E}$$

$$v_{out} = R_E i_e = R_E (1+\beta) i_b$$

$$v_{out} = \frac{R_E (\beta+1) v_{sig}}{R_S + r_\pi + (\beta+1) R_E}$$

$$\boxed{A_V = \frac{v_{out}}{v_{sig}} = \frac{R_E v_{sig}}{\frac{R_S + r_\pi}{(\beta+1)} + R_E} \approx 1}$$

Small Signal Analysis – Voltage Gain - cont.



$$\frac{v_{out}}{v_{sig}} = \frac{R_E}{\frac{R_S + r_\pi}{(\beta+1)} + R_E}$$

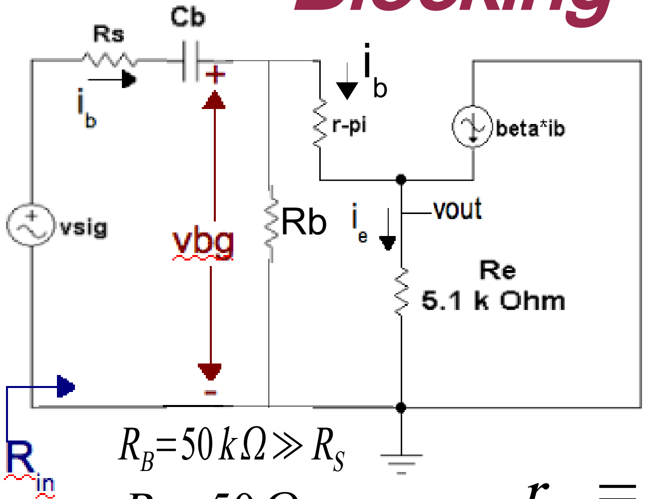
Since, typically:

$$\frac{R_S + r_\pi}{(\beta+1)} \ll R_E$$

$$\boxed{A_V = \frac{v_{out}}{v_{sig}} \approx \frac{R_E}{R_E} = 1}$$

Note: A_V is non-inverting

Blocking Capacitor - C_B - Selection



$R_B = 50\,k\Omega \gg R_S$

$R_S = 50\,\Omega$

Use the base current expression:

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

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

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

To obtain the base to ground resistance of the transistor:
This transistor input resistance is in parallel with the *50 k Ω* R_B, forming the total amplifier input resistance:

$$R_{in} = R_S + R_B \| r_{bg} \approx R_B \| r_{bg} = \frac{515}{(515+50)} 50\,k\Omega = 45.6\,k\Omega$$

C_B – Selection cont.

Choose C_B such that its reactance is $\leq 1/10$ of R_{in} at ω_{min}:

$$\frac{1}{\omega C_B} = \frac{R_{in}}{10}$$

$$C_B \geq \frac{10}{\omega_{min} R_{in}}$$

$$\boxed{C_B \geq \frac{10 \cdot 10^{-7}}{1.25 \cdot 0.46} \approx 1.73 \mu F}$$

Assume the lowest frequency is $20\ Hz$:

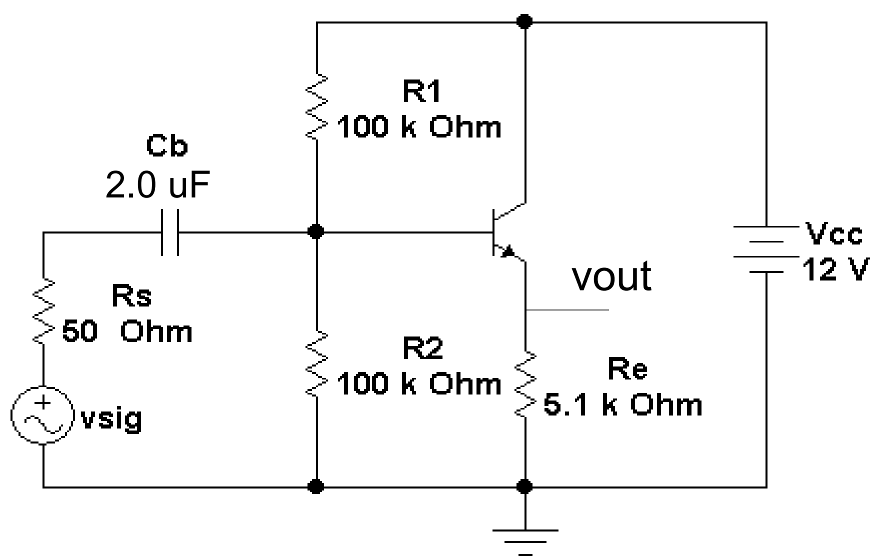
$$\omega_{min} = 2\pi 20 \approx 125 = 1.25 \cdot 10^2$$

$$\beta = 100$$

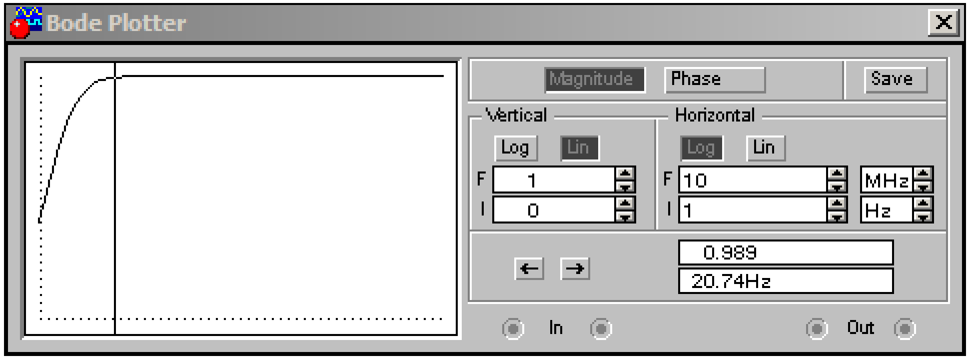
$$R_{in} \approx 46\ k\Omega$$

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}.

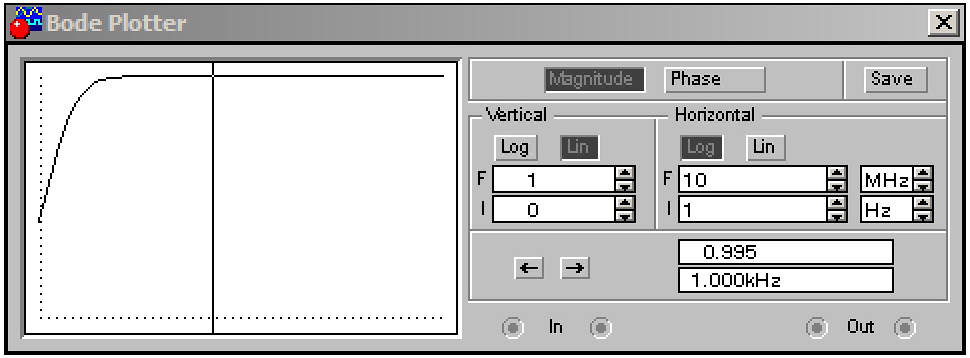
Final Design



Multisim Simulation Results

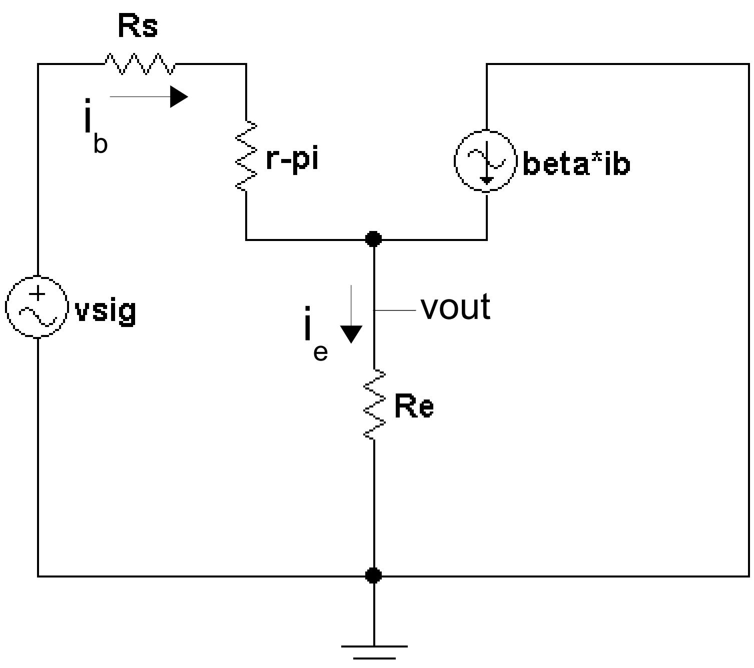


20 Hz. Data



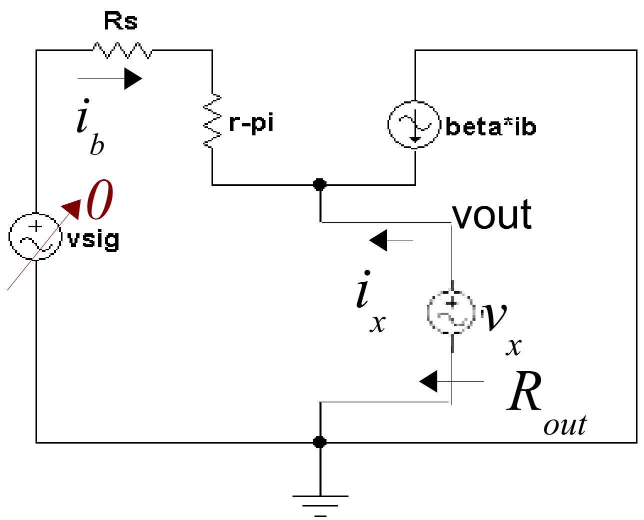
1 Khz. Data

Of What value is a Unity Gain Amplifier?



To answer this question, we must examine the *output impedance* of the amplifier and its *power gain*.

Emitter Follower Output Resistance



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

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

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

$$R_B = 50\,k\Omega \gg R_S$$

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

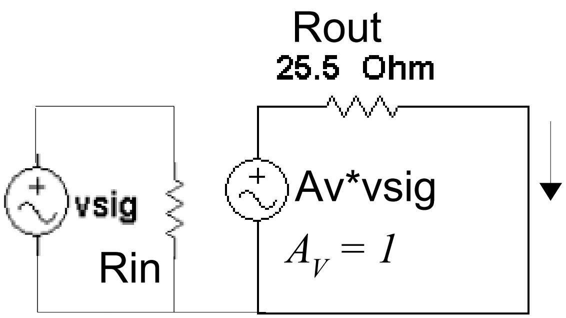
Assume:

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

$$\beta = 100 \qquad R_S = 50\,\Omega$$

$$R_{out} \approx \frac{2550}{100} = 25.5\,\Omega$$

Multisim Verification of R_{out}



$i_{sc} = i_x$

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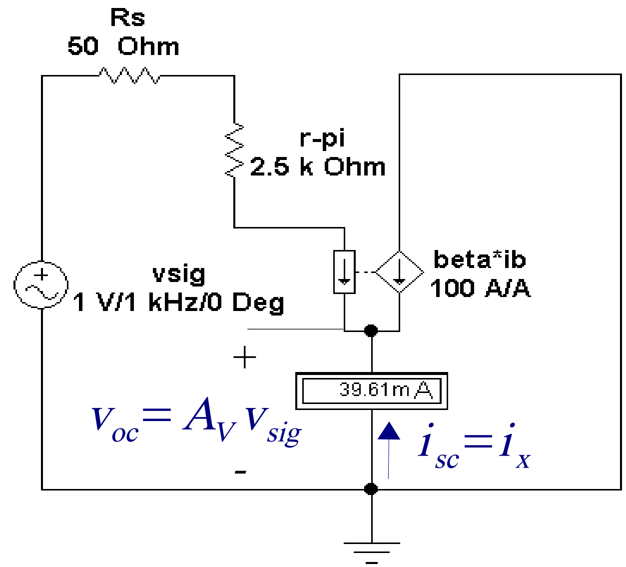


$v_{oc} = A_V v_{sig}$

$i_{sc} = i_x$

$$i_x = -(1+\beta) i_x$$

$$v_{sig} = R_S i_b + r_\pi i_b$$

$$R_{out} = \frac{A_V v_{sig}}{i_x} = \frac{R_S + r_\pi}{1+\beta}$$

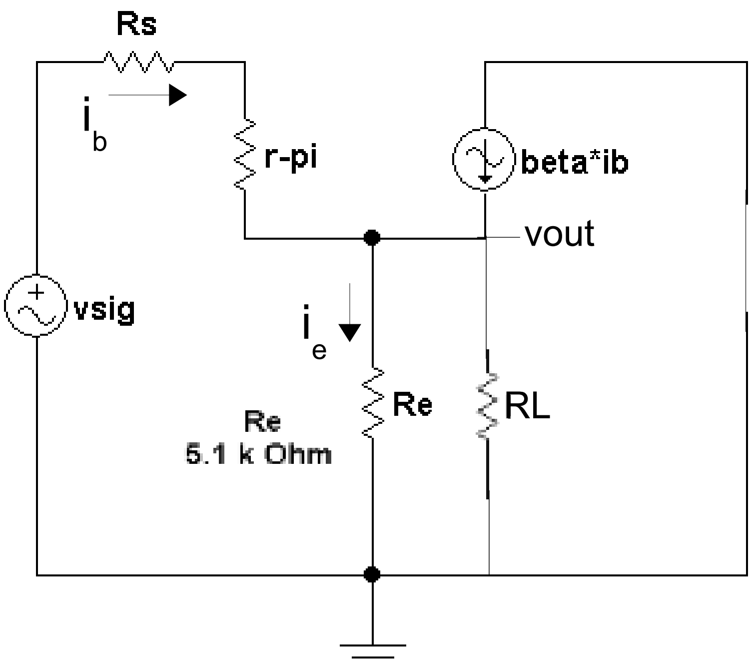
$$R_{in} = R_S + r_\pi + (\beta+1) R_E \| R_L \approx (\beta+1) R_L$$

Thevenin equivalent for the short-circuited emitter follower. If β was 200, as for most good NPN transistors, R_{out} would be lower - close to $12\ \Omega$.

Multisim short circuit check ($\beta = 100$, v_{out} = v_{sig}):

$$R_{out} = \frac{v_{oc}}{i_{sc}} = \frac{A_V v_{sig(rms)}}{i_{sc(rms)}} = \frac{1}{0.0396} = 25.25\,\Omega$$

Equivalent Circuits with Load R_L



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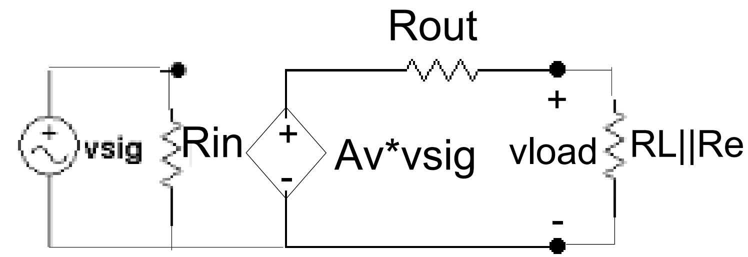
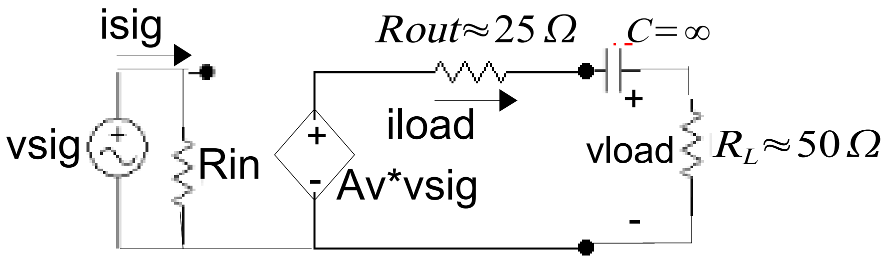


$$R_{out}=\frac{V_{sig(rms)}}{i_{sc(rms)}}=\frac{1}{0.0396}=25.25\,\Omega$$

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

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:



$$A_V \approx 1$$

$$v_{load} = \frac{R_L A_V v_{sig}}{R_L + R_{out}} = \frac{50}{75} v_{sig} = \frac{2}{3} v_{sig}$$

$$i_{load} = \frac{A_V v_{sig}}{R_{out} + R_L} = \frac{v_{sig}}{75}$$

$$p_{load} = v_{load} i_{load} = \frac{2}{225} v_{sig}^2$$

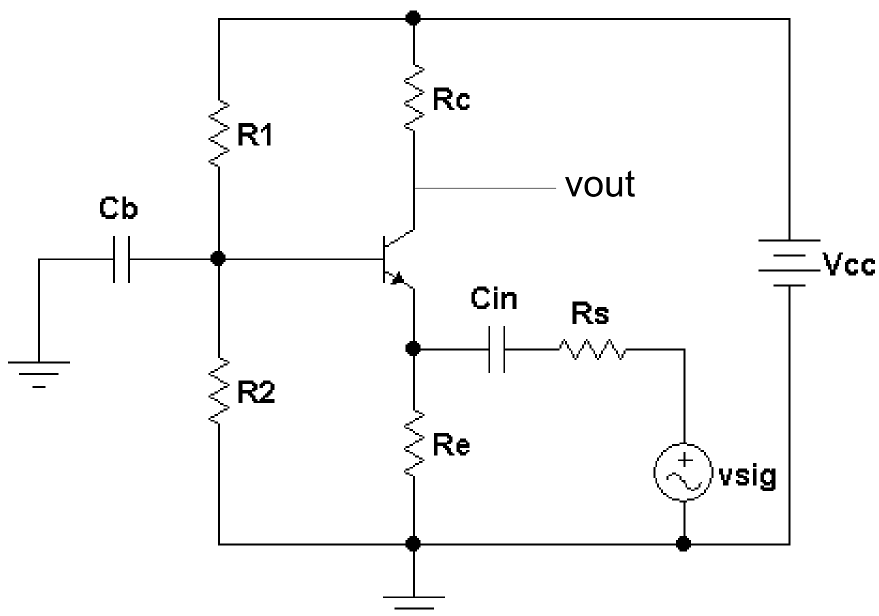
$50\,\Omega$ load is in parallel with $5.1k\Omega$ R_E and dominates:

$$i_{sig} = i_b = \frac{v_{sig}}{R_{in}} \approx \frac{v_{sig}}{(\beta+1) R_E \| R_L} \approx \frac{v_{sig}}{101 \cdot 50}$$

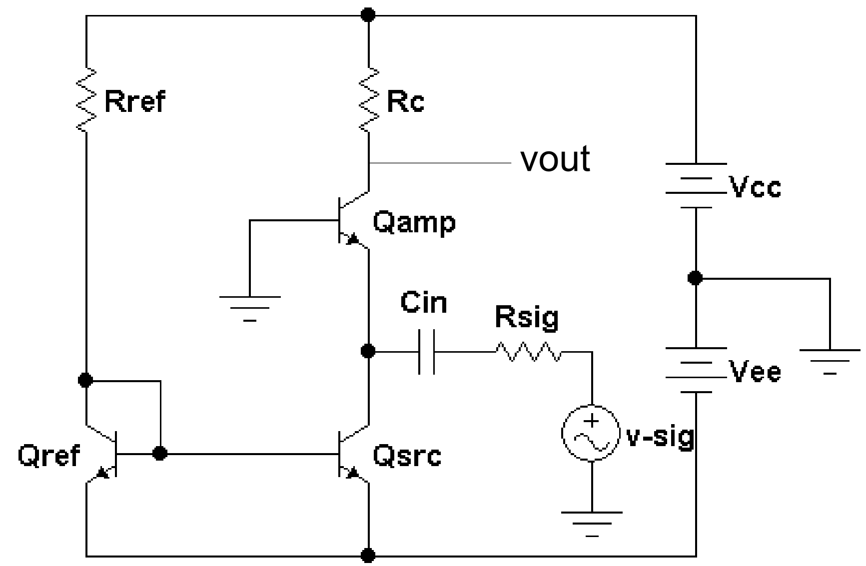
$$p_{sig} = v_{sig} i_{sig} \approx \frac{1}{5000} v_{sig}^2$$

$$\boxed{G_{pwr} = \frac{p_{load}}{p_{sig}} = \frac{2(5000)}{225} = 44.4 \gg 1}$$

The Common Base Amplifier



Voltage Bias Design



Current Bias Design

Common Base Configuration

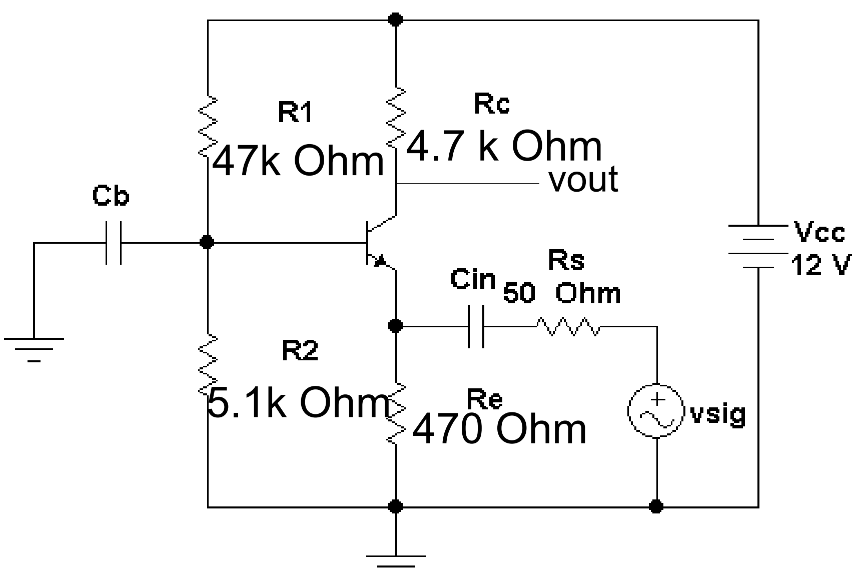
Both voltage and current biasing follow the same rules as those applied to the common emitter amplifier.

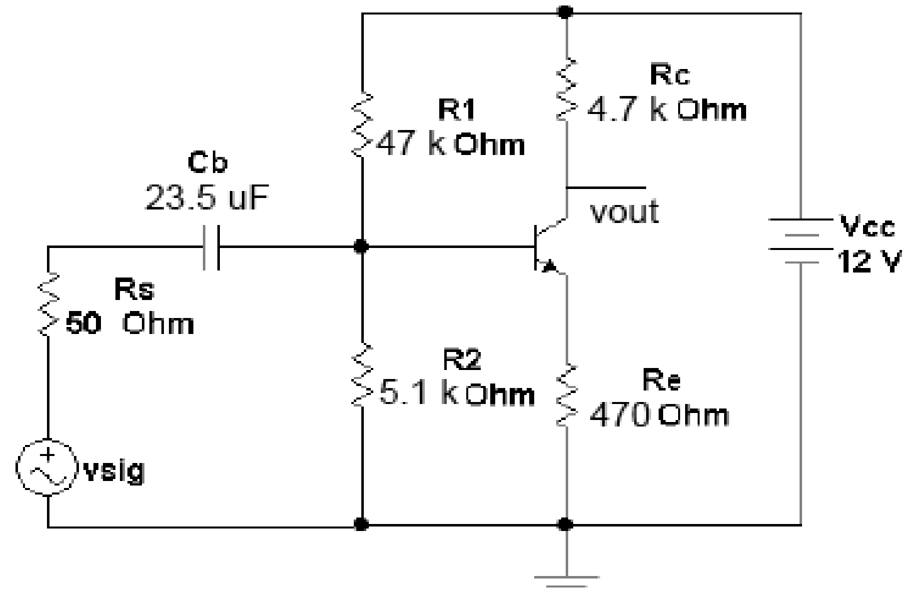
As before, insert a blocking capacitor in the input signal path to avoid disturbing the dc bias.

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.

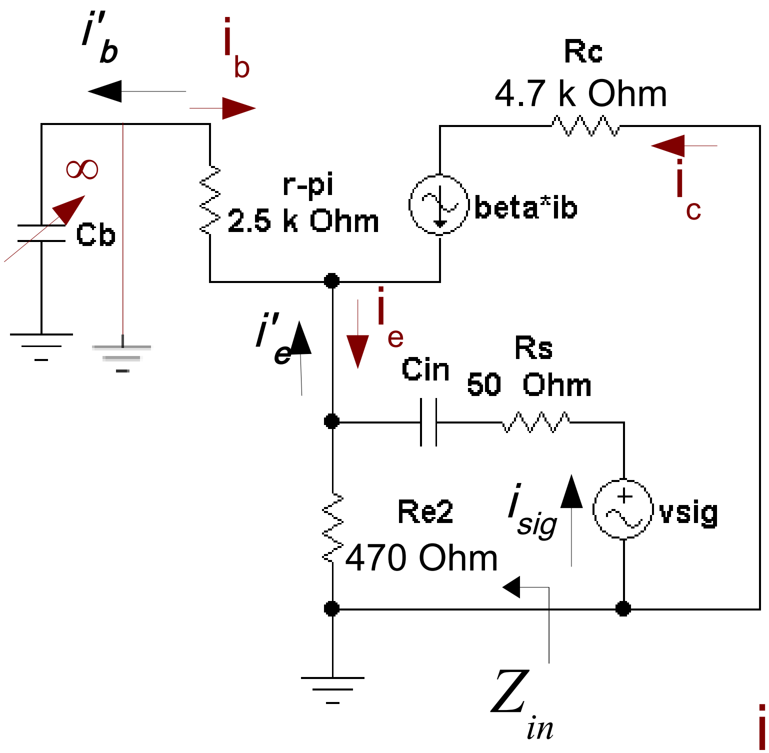
Voltage Bias Common Base Design





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_{E2}:

$$v_{Re2} = \frac{R_{E2} \| r_e}{R_{E2} \| r_e + R_S + \dfrac{1}{j\omega C_{IN}}} v_{sig} \qquad r_e = \frac{r_\pi}{1+\beta}$$

ideally $\quad v_{Re2} = \dfrac{R_{E2} \| r_e}{R_{E2} \| r_e + R_S} v_{sig}$ for $\omega \geq \omega_{min}$

$$\frac{1}{\omega_{min} C_{IN}} \ll R_S + \underbrace{R_{E2} \| r_e}_{r_e} \Rightarrow \frac{1}{\omega_{min} C_{IN}} = \frac{R_S + r_e}{10} \Rightarrow \boxed{C_{IN} = \frac{10}{\omega_{min}(R_S + r_e)}}$$

Determine C_{IN} cont.

A suitable value for C_{IN} for a *20 Hz* lower frequency:

$$\omega_{min} C_{IN}(R_S + r_e) \gg 1 \Rightarrow C_{IN} \geq \frac{10}{2\pi\,\omega_{min}(R_S + r_e)} = \frac{10}{2\pi\,20 \cdot 75}\,F$$

$$\boxed{C_{IN} = \frac{10}{125.6 \cdot 75} \approx 1062\,\mu F\ !}$$

Not too practical!

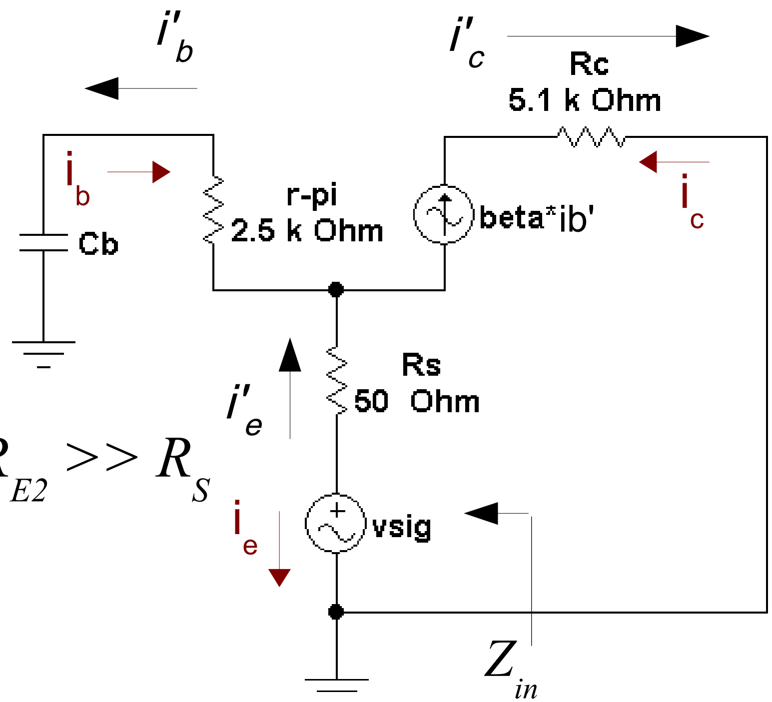
Must choose smaller value of C_{IN}.

1. Choose: $\omega_{min} C_{IN}(R_S + r_e) = 1$

or

2. Choose larger ω_{min}

Small-signal Analysis - C_B



$R_{E2} >> R_S$

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

Note the reference current reversals (due to v_{sig} polarity)!

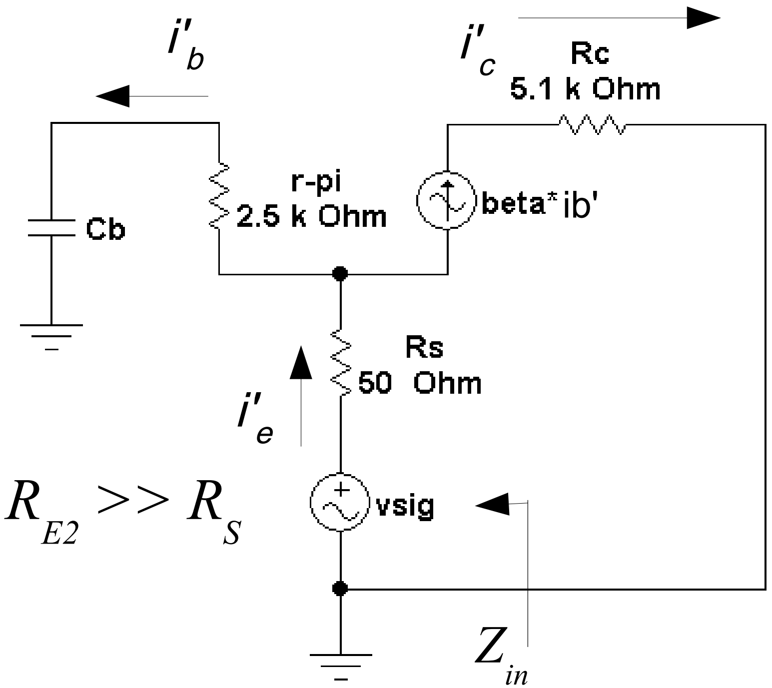
$$v_{sig}=R_S i_e' + \left(r_\pi + \frac{1}{j\omega C_B} \right) i_b'$$

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

$$i_e' = \frac{\beta+1}{(\beta+1) R_S + r_\pi + \frac{1}{j\omega C_B}} v_{sig}$$

Determine $Z_{in}=\frac{v_{sig}}{i_e'}$

Determine – C_B



$R_{E2} >> R_S$

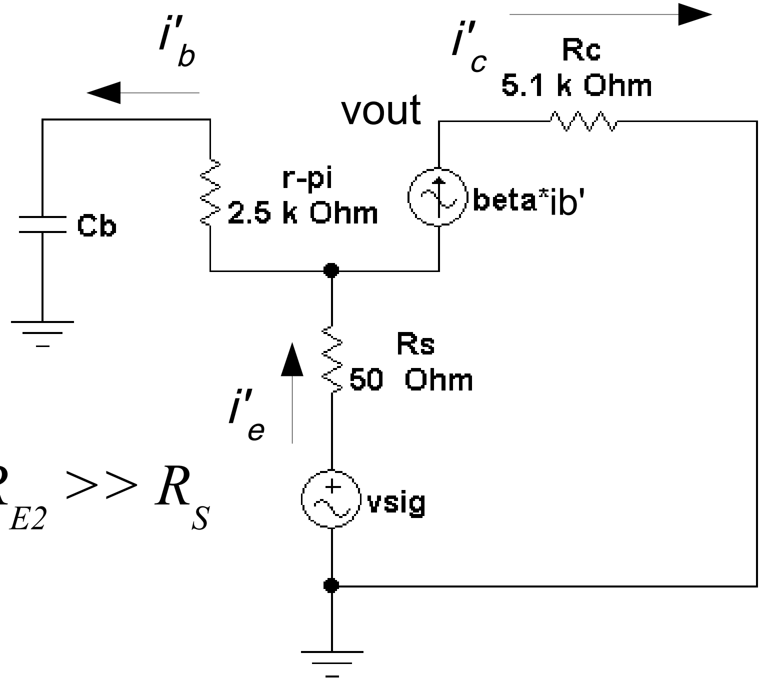
$$i'_e = \frac{\beta+1}{(\beta+1)R_S + r_\pi + \frac{1}{j\omega C_B}} v_{sig}$$

$$i'_e = \frac{v_{sig}}{R_S + \frac{1}{\beta+1}\left(r_\pi + \frac{1}{j\omega C_B}\right)}$$

$$Z_{in} = \frac{v_{sig}}{i'_e} = R_S + \frac{1}{\beta+1}\left(r_\pi + \frac{1}{j\omega C_B}\right)$$

ideally $Z_{in} \approx R_S + \frac{r_\pi}{\beta+1} \Rightarrow \frac{1}{\omega C_B} \ll (\beta+1)R_S + r_\pi$ for $\omega \geq \omega_{min}$

Determine - C_B cont.



$R_{E2} >> R_S$

For $\omega \geq \omega_{min}$

$$Z_{in} \approx R_S + \frac{r_\pi}{\beta+1} \Rightarrow \frac{1}{\omega C_B} \ll (\beta+1) R_S + r_\pi$$

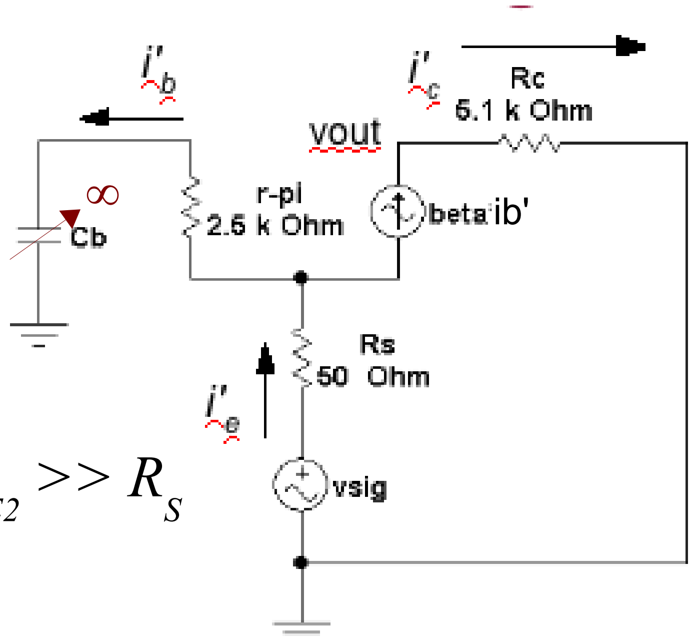
Choose:

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

i.e.

$$C_B \geq \frac{10}{2\pi 20\left((100+1)50+2500\right)} = 10.5 \mu F$$

Small-signal Analysis – Voltage Gain



$R_{E2} >> R_S$

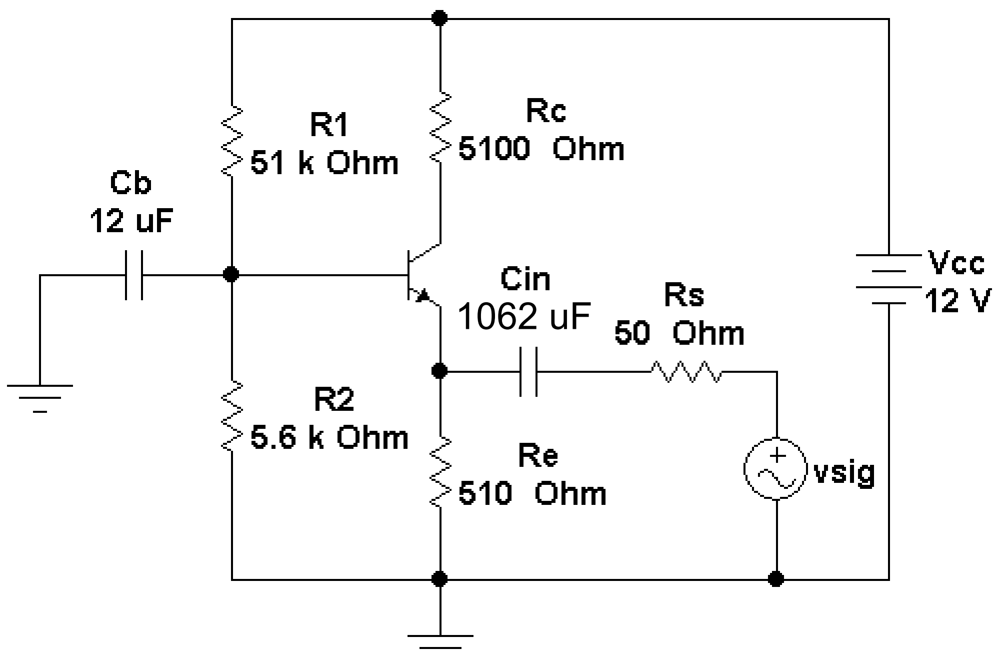
Assume: $C_B = C_{IN} = \infty$

$$i'_e \approx \frac{1}{R_S + \frac{r_\pi}{\beta+1}} v_{sig} = \frac{1}{(R_S + r_e)} v_{sig}$$

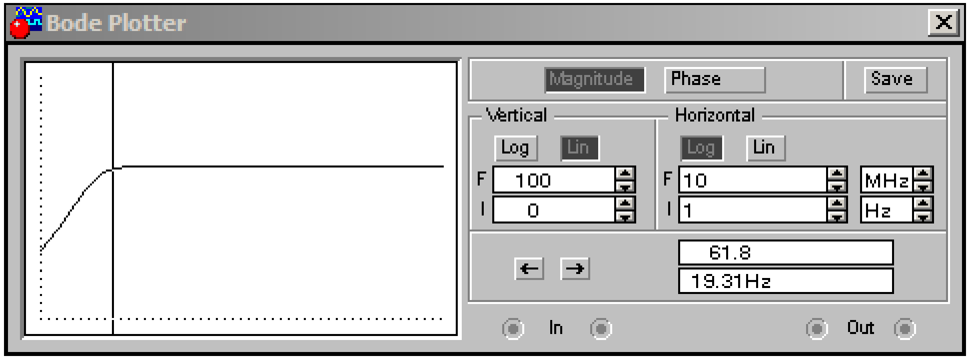
$$v_{out} = R_C i'_c = \alpha R_C i'_e = \frac{\beta}{\beta+1} \frac{R_C}{R_S + r_e} v_{sig}$$

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

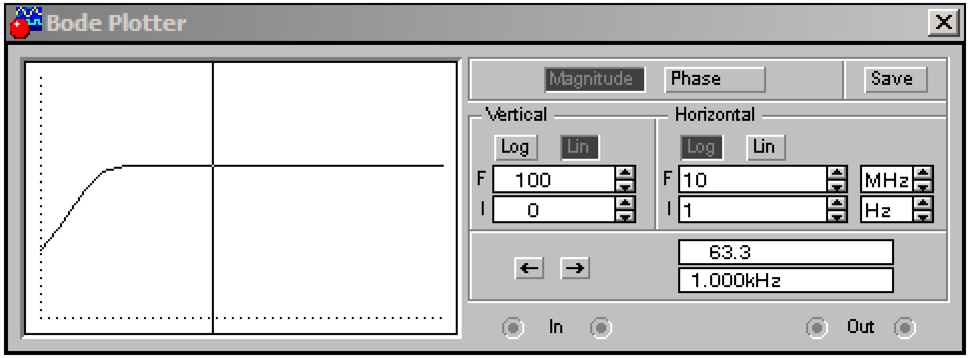
Multisim Simulation



Multisim Frequency Response



20 Hz. response



1 KHZ. Response