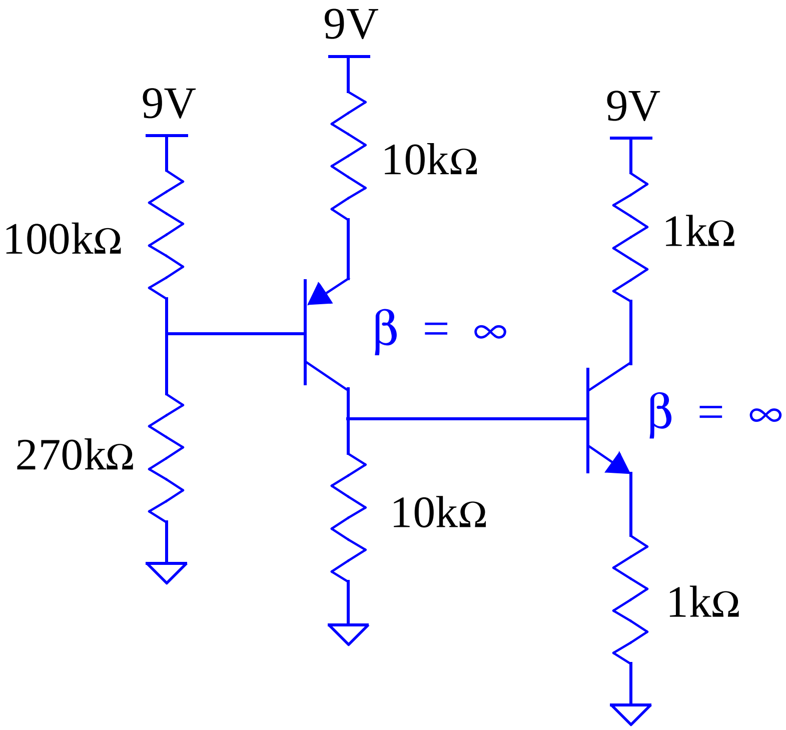
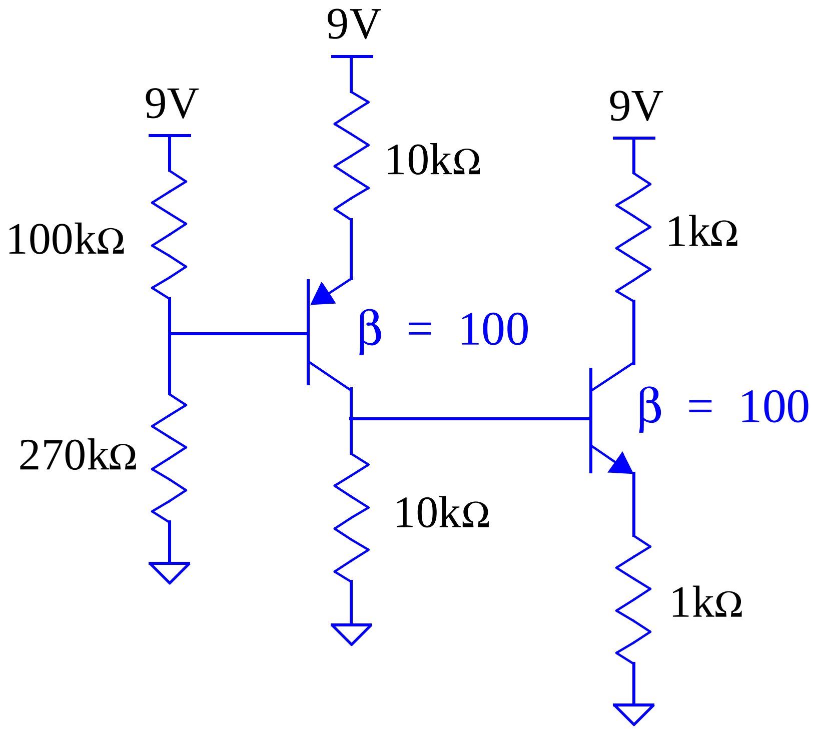
dc Bias Point Calculations

- Find all of the node voltages assuming infinite current gains



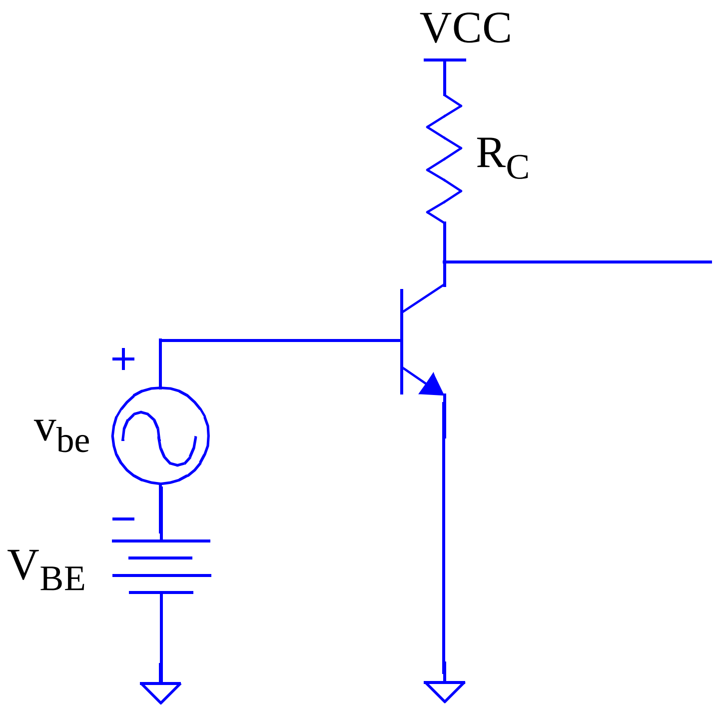
dc Bias Point Calculations

- Find all of the node voltages assuming *finite* current gains



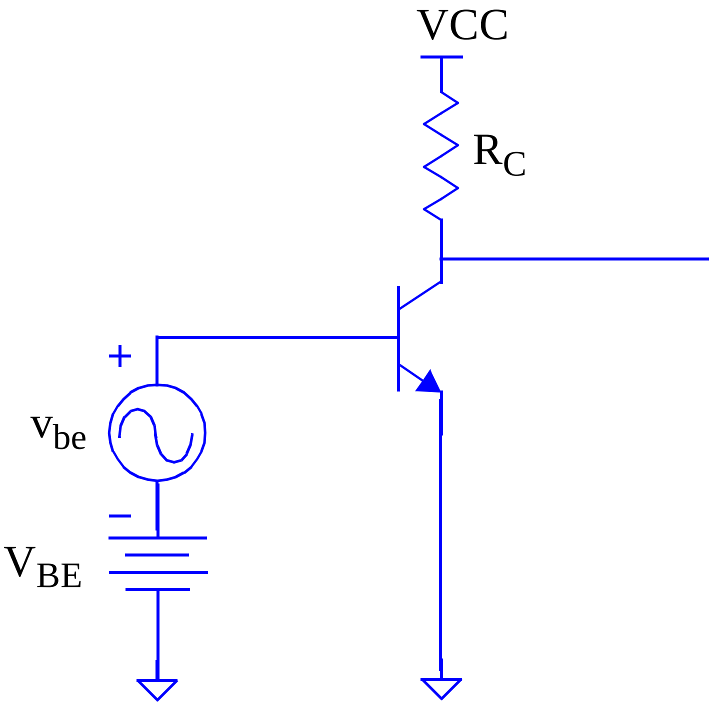
Biasing and Small Signal Approximations

- Bias the transistor into the linear region, then use it as a linearized amplifier for small ac signals
- Select R_C so that the transistor will not saturate:



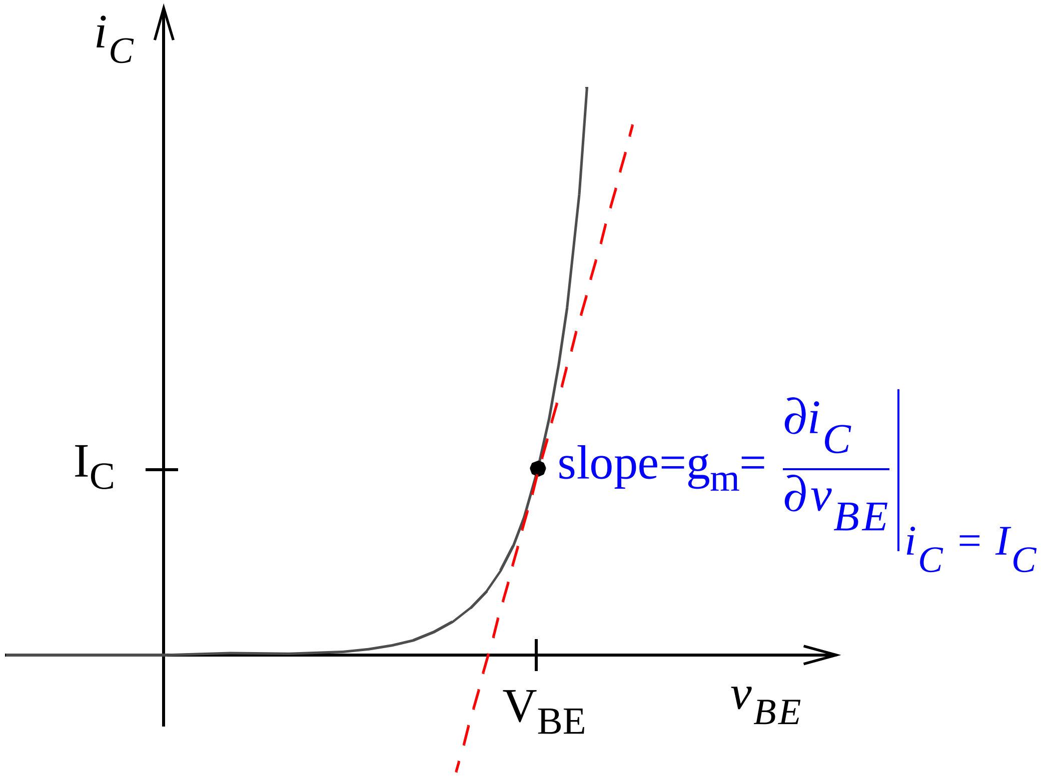
Small Signal Approximations

- $v_{BE} = V_{BE} + v_{be}$; $i_C = I_C + i_c$ [Note the variable notation]

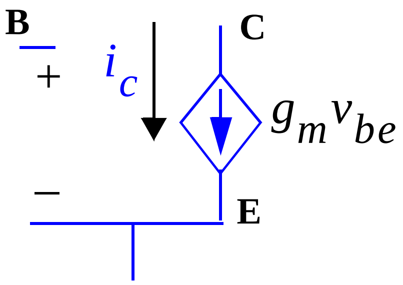


Transconductance

- Small signal amplifier behaves like a linear voltage controlled current source
- Bias to a value of I_C to establish the transconductance, g_m, that you want

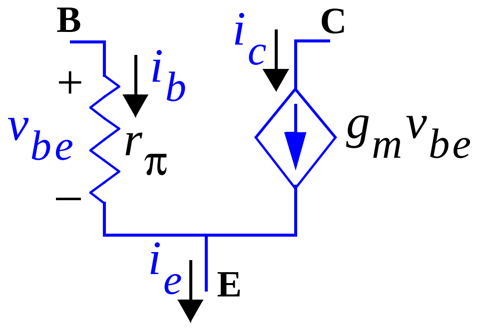


$$\text{slope}=g_m=\left.\frac{\partial i_C}{\partial v_{BE}}\right|_{i_C = I_C}$$



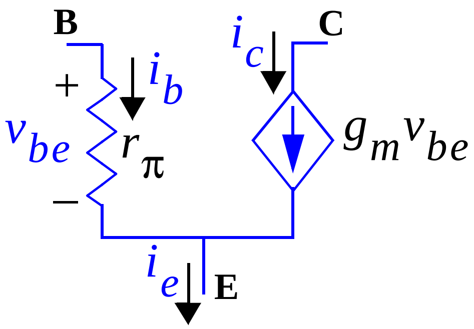
Input Impedance

- How do we model the small signal behavior as viewed from the input signal?
- What is the small signal change in v_{be} due to a small signal change in i_b?



Emitter Impedance

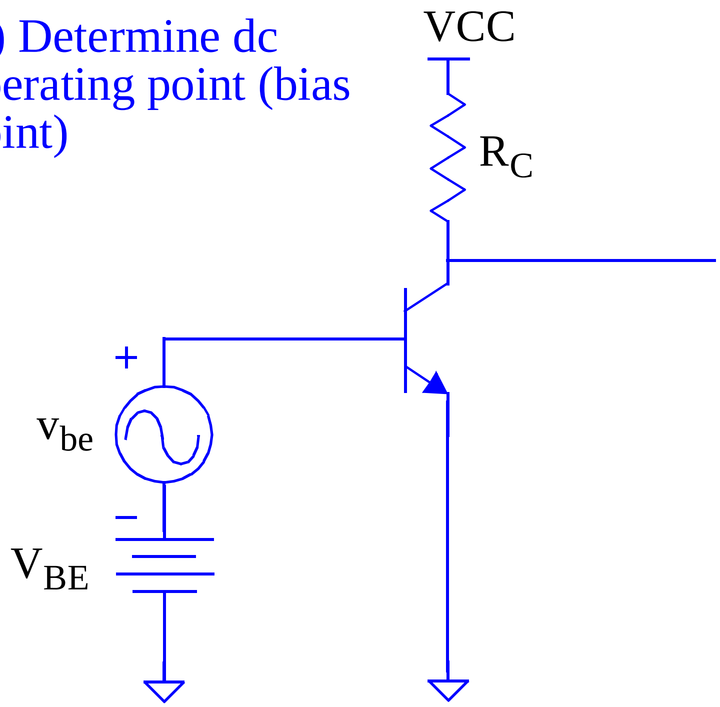
- What is the impedance “seen” by the emitter?



Small Signal Analysis

- Every response voltage and current has a dc component and a small signal (steady state) component
- dc sources cause the dc portion of the responses
- ac sources cause the ac portion of the responses
- Example:

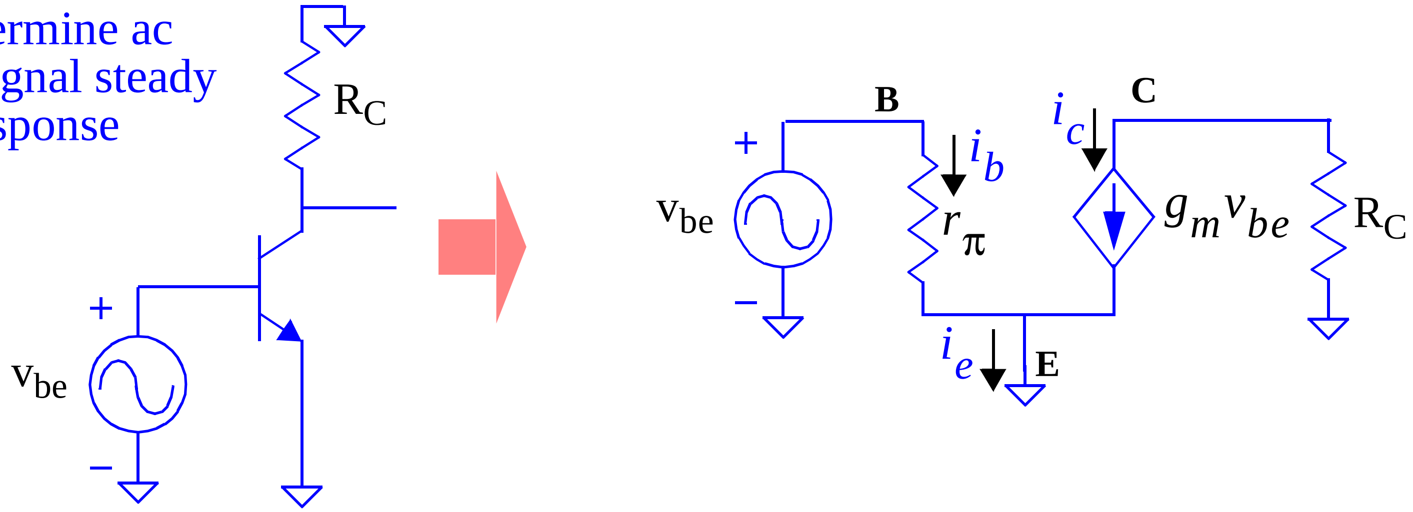
1.) Determine dc operating point (bias point)



Small Signal Analysis

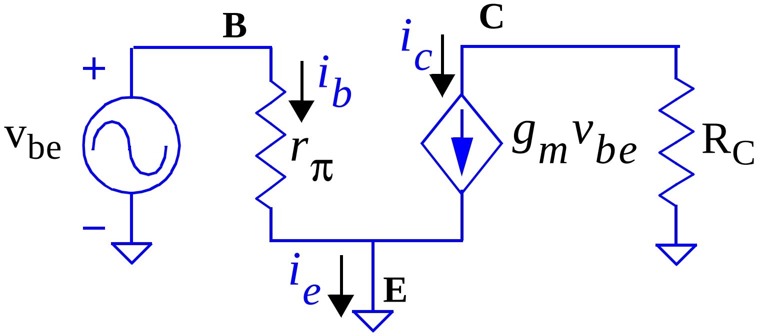
- Then the ac portion of the response can be determined with all of the dc sources removed:

2.) Determine ac small signal steady state response



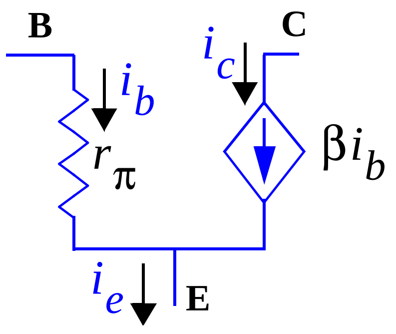
Small Signal Analysis

- Models linearized approximation of ac response about dc operating point
- Calculating i_b and i_c is sufficient, but we know that $i_e = v_{be}/r_e$

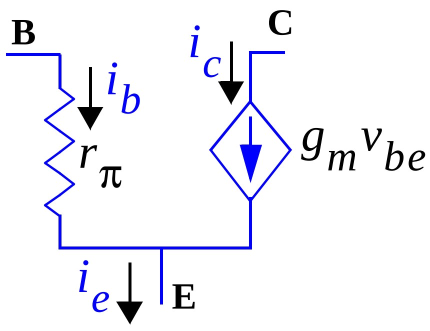


Hybrid-π Small Signal Model

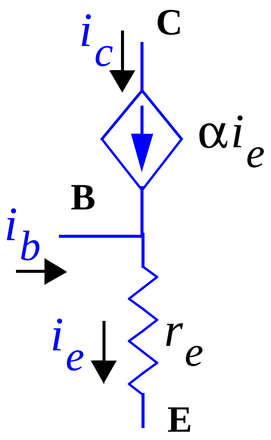
- Another way to represent the amplification of the input signal



Identical in behavior

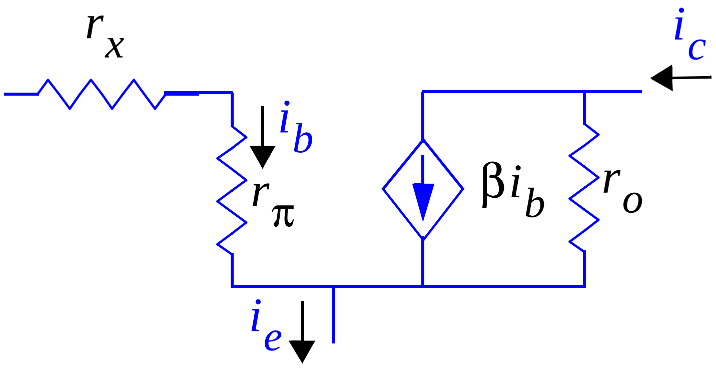


- Or, use i_c and i_e to specify i_b



Small Signal Model

- Some other parameters may be base-resistance and C-E resistance due to Early voltage



- At high frequencies we would have to include the impedances due to the parasitic capacitors

Small Signal Capacitance Models

- At high frequency we must also model the parisitic capacitances
- The stored based charge is modeled by a diffusion capacitance
- Although it is nonlinear, the small signal difficusion capacitance is linearized about the operating point

$$Q_n = \tau_F i_C \quad \Rightarrow \quad C_{de} = \tau_F \left. \frac{di_C}{dv_{BE}} \right|_{i_C = I_C}$$

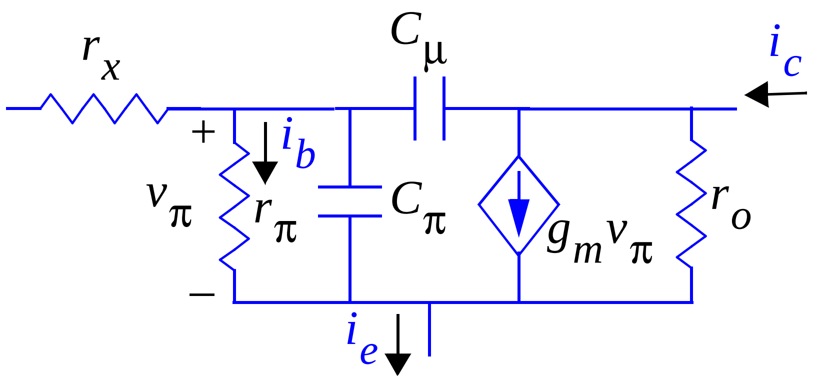
- There are also junction capacitors between emitter-base and base-collector

$$C_{je} = \frac{C_{je0}}{\left(1 - \dfrac{v_{BE}}{v_{0e}}\right)^m} \qquad C_{je} \cong 2C_{je0}$$

$$\Rightarrow$$

$$C_{jc} = \frac{C_{jc0}}{\left(1 - \dfrac{v_{BC}}{v_{0c}}\right)^m} \qquad C_{jc} \cong 2C_{jc0}$$

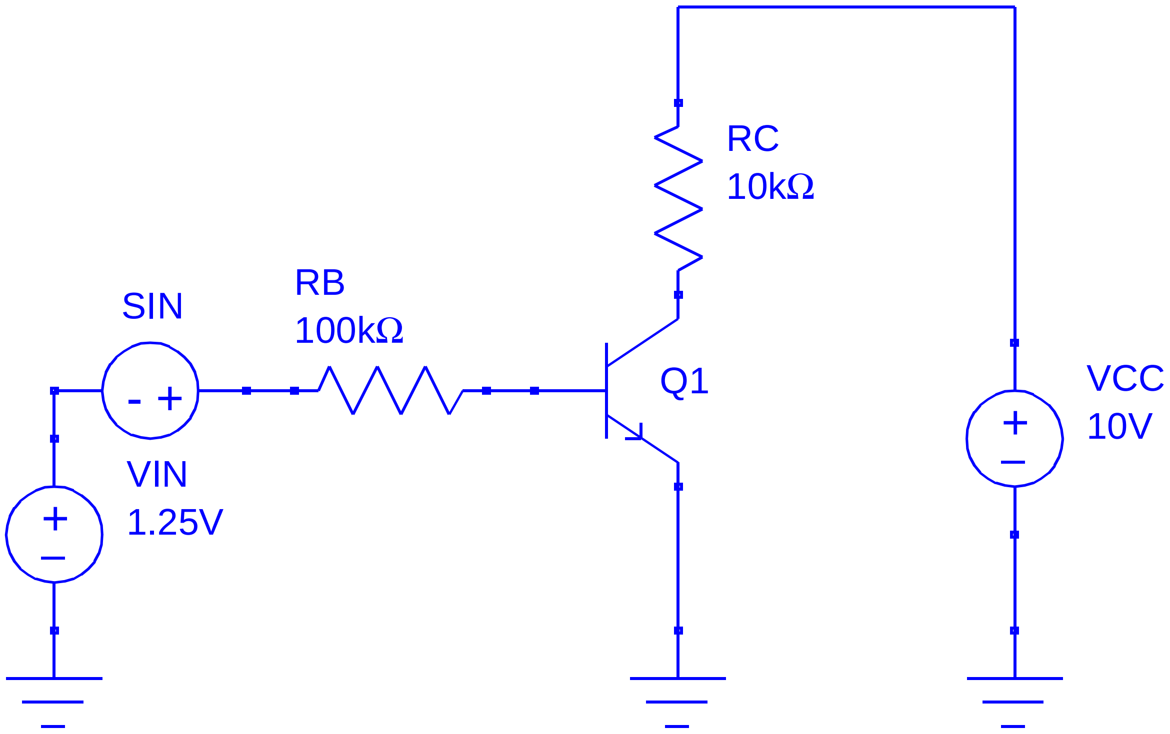
High Frequency Hybrid-π Model



- Ground the emitter, short the collector the emitter, and drive the base
- Calculate current gain as a function of frequency to define unity gain bandwidth of the transistor

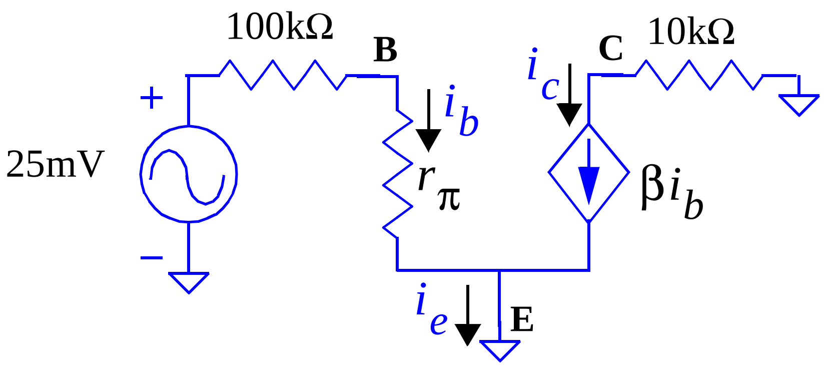
Example

- Analyze the small signal steady state response



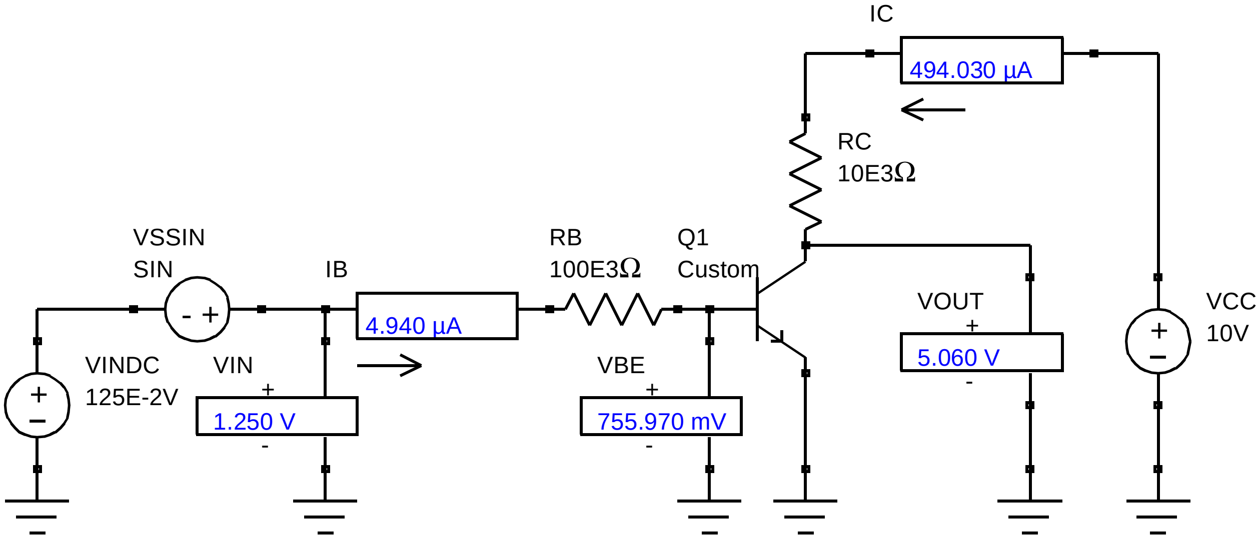
Example

- The gain is easily identified from the small signal model
- For a common emitter configuration, the hybrid-π model is the easiest to analyze



SPICE Result

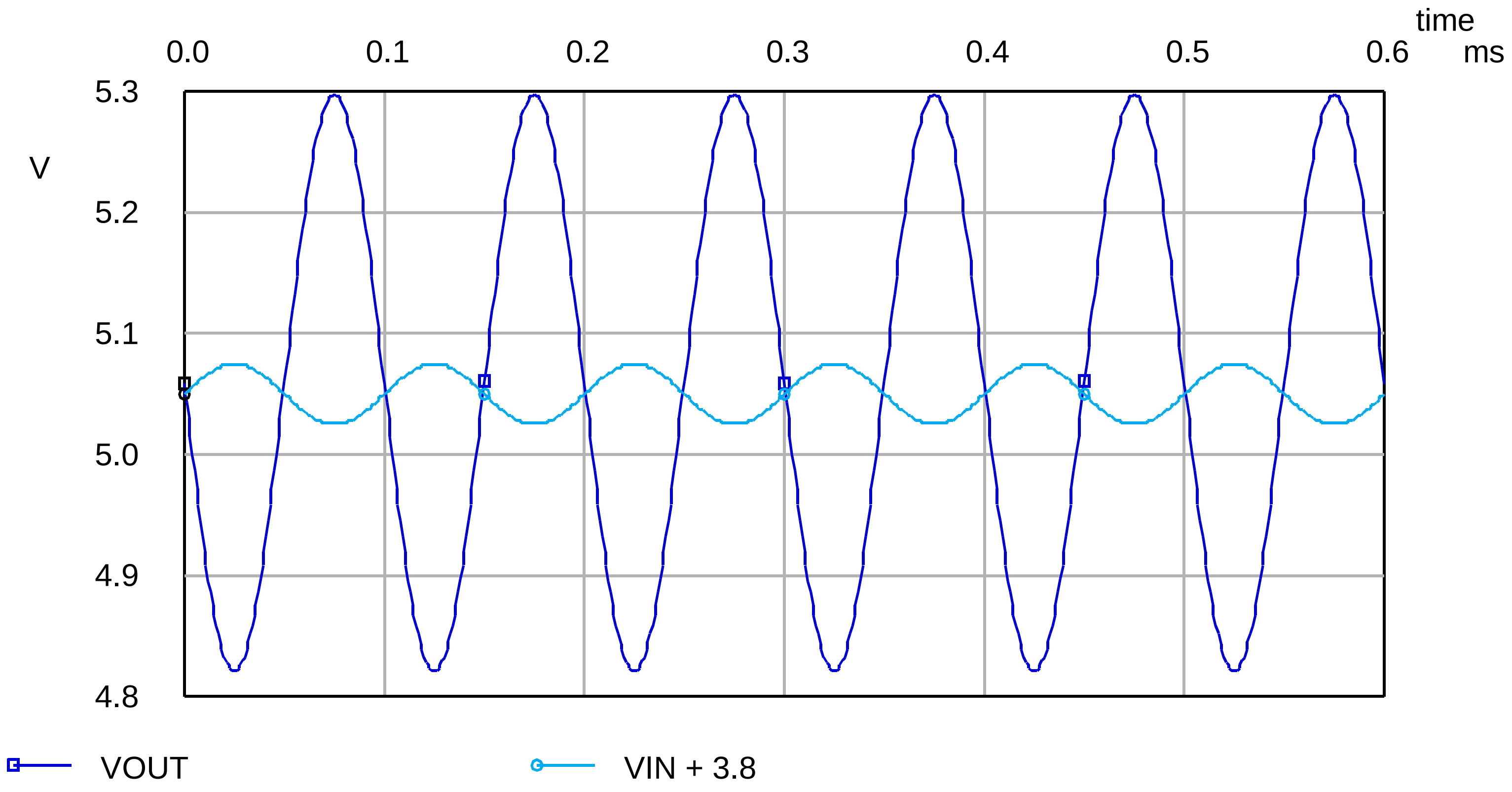
- Bias point solution from SPICE

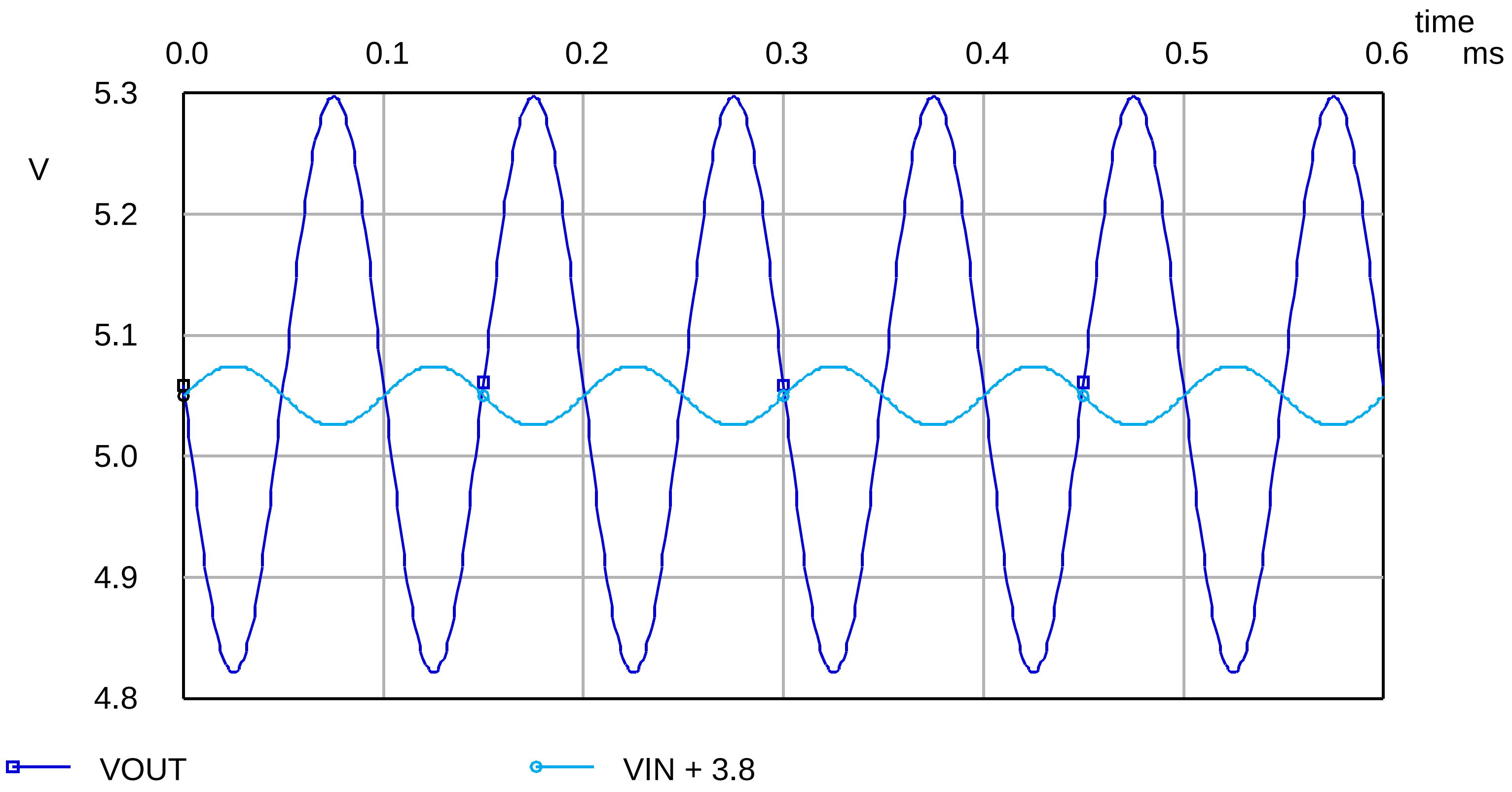


SPICE Result Time Domain SPICE Result

- For this example we can perform a transient analysis to get a reasonable approximation of what the steady state sinusoidal response looks like. Why?

- Why is there a phase shift between input and output?



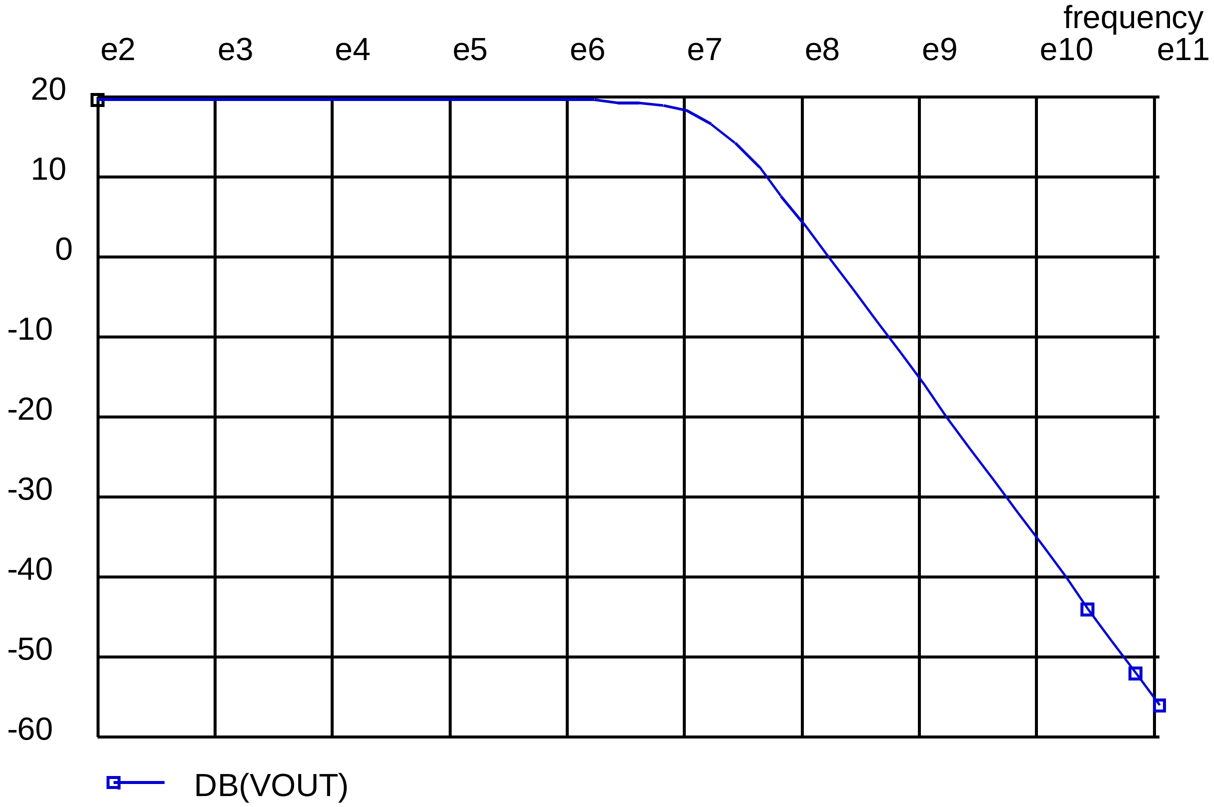


- Is the circuit really behaving like a linear amplifier?

- What does the ac *small signal* frequency response look like?

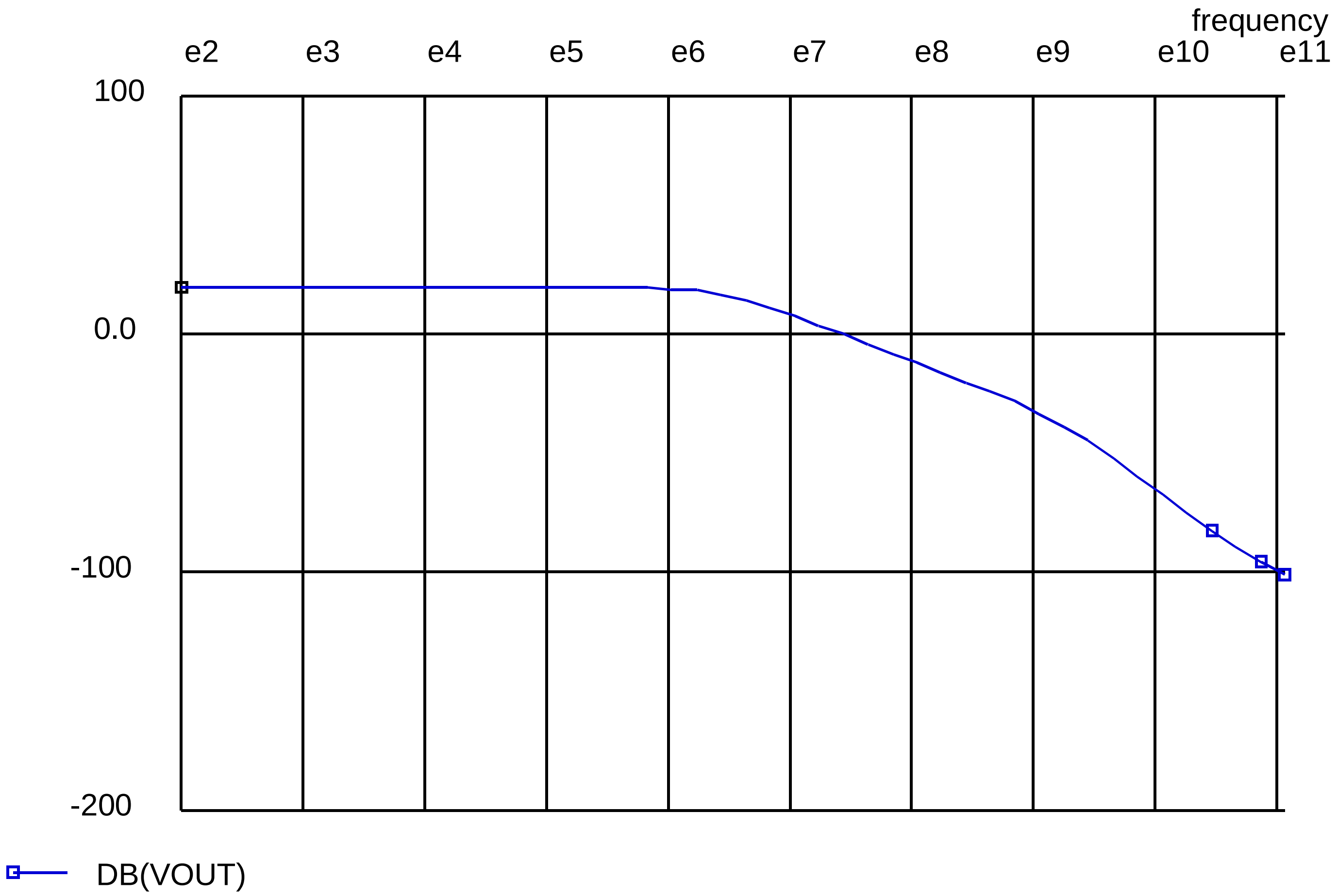
SPICE Frequency Response

- *We have to add the parameters to the SPICE model which represent the capacitance effects* before we can observe them in the ac analysis
- e.g. TF = 0.1ns --- *Diffusion Capacitance*



SPICE Frequency Response

- Also adding CJE = 0.1pF



SPICE Frequency Response

- Small signal models must include capacitance and transit times when we are interested in high frequency responses
- These capacitors are nonlinear, but treated as linearized values about their dc operating point (same as transconductance, etc.)
- The default SPICE model may not even include these parameters since it unnecessarily complicates the model for a simulation of the mid-band frequencies
- For the mid-band frequency range of interest we can view these capacitors as open