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

\[ \beta = 100 \]
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:

![Circuit Diagram](image-url)
Small Signal Approximations

- $v_{BE} = V_{BE} + v_{be}; \quad i_C = I_C + i_c$  [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

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

![Diagram of Emitter Impedance](image)
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 $i_e = \frac{v_{be}}{r_e}$
Hybrid-$\pi$ Small Signal Model

- Another way to represent the amplification of the input signal

- Or, use $i_c$ and $i_e$ to specify $i_b$
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 parasitic capacitances.
- The stored based charge is modeled by a diffusion capacitance.
- Although it is nonlinear, the small signal diffusion capacitance is linearized about the operating point.

\[ Q_n = \tau_F i_C \quad \Rightarrow \quad C_{de} = \tau F \frac{d i_C}{d v_{BE}} \bigg|_{i_C = I_C} \]

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

\[ C_{je} = \frac{C_{je0}}{\left(1 - \frac{v_{BE}}{v_{0e}}\right)^m} \quad \Rightarrow \quad C_{je} \approx 2C_{je0} \]
\[ C_{jc} = \frac{C_{jc0}}{\left(1 - \frac{v_{BC}}{v_{0c}}\right)^m} \quad \Rightarrow \quad C_{jc} \approx 2C_{jc0} \]
Ground the emitter, short the collector to 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
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?
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 $C_{JE} = 0.1\text{pF}$
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.