PNP BJT Biasing

• Note that the emitter is biased at a higher potential than the base and the collector.
Small-Signal Analysis

PNP BJT Small-Signal Model

• The small-signal model for a PNP transistor is **identical to that of an NPN transistor**.
  – Note that the polarity of the small-signal currents and voltages are defined to be in the opposite direction with respect to the large-signal model. This is OK, because the small-signal model is used only to determine changes in currents and voltages.
Small-Signal Model Example 1

Note that the small-signal model is identical to that in the previous example.

Small-Signal Model Example 2
Small-Signal Model Example 3

• Note that the small-signal model is identical to that in the previous examples.

BJT Amplifiers: Overview

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Voltage Amplifier

- In an ideal voltage amplifier, the input impedance is infinite and the output impedance is zero.
- In reality, the input and output impedances depart from their ideal values.

Input/Output Impedances

- The figures below show how input and output impedances are determined.
  - All independent sources are set to zero.

\[
\text{impedance } = \frac{v_x}{i_x}
\]
Input Impedance Example

- Note that input/output impedances are usually regarded as small-signal quantities.
  - The input impedance is obtained by applying a small change in the input voltage and finding the resultant change in the input current:

\[
\frac{v_x}{i_x} = r_{\pi}
\]

Impedance at a Node

- When calculating I/O impedances at a port, we usually ground one terminal. We often refer to the “impedance seen at a node” rather than the impedance between two nodes (i.e. at a port).
Impedance seen at the Collector

- The impedance seen at the collector is equal to the intrinsic output impedance of the transistor, if the emitter is grounded.

\[ R_{\text{out}} = r_o \]

Impedance seen at the Collector

- The impedance seen at the collector is equal to the intrinsic output impedance of the transistor, if the emitter is grounded.

\[ R_{\text{out}} = r_o \]
Impedance seen at the Emitter

- The impedance seen at the emitter is approximately equal to the inverse of its transconductance, if the base is grounded.

\[
\frac{v_e}{i_s} = \frac{1}{g_m + \frac{1}{r_e}}
\]

\[
R_{out} \approx \frac{1}{g_m}
\]

\[V_A = \infty\]

\[r_b = \infty\]
Summary of BJT Impedances

1. Looking into the base, the impedance is \( r_\pi \) if the emitter is (ac) grounded.
2. Looking into the collector, the impedance is \( r_o \) if emitter is (ac) grounded.
3. Looking into the emitter, the impedance is \( 1/g_m \) if base is (ac) grounded and Early effect is neglected.

Biasing of BJT

- Transistors must be biased because
  1. They must operate in the active region, and
  2. Their small-signal model parameters are set by the bias conditions.
**DC Analysis vs. Small-Signal Analysis**

- Firstly, DC analysis is performed to determine the operating point and to obtain the small-signal model parameters.
- Secondly, independent sources are set to zero and the small-signal model is used.

**Simplified Notation**

- Hereafter, the voltage source that supplies power to the circuit is replaced by a horizontal bar labeled $V_{CC}$ and input signal is simplified as one node labeled $v_{in}$. 
Example of Bad Biasing

• The microphone is connected to the amplifier in an attempt to amplify the small output signal of the microphone.
• Unfortunately, there is no DC bias current running through the transistor to set the transconductance.
Another Example of Bad Biasing

• The base of the amplifier is connected to $V_{CC}$, trying to establish a DC bias.
• Unfortunately, the output signal produced by the microphone is shorted to the power supply.

![Diagram](image1)

Another Example of Bad Biasing

• The base of the amplifier is connected to $V_{CC}$, trying to establish a DC bias.
• Unfortunately, the output signal produced by the microphone is shorted to the power supply.

![Diagram](image2)
Biasing with Base Resistor

- Assuming a constant value for $V_{BE}$, one can solve for both $I_B$ and $I_C$ and determine the terminal voltages of the transistor.
- However, the bias point is sensitive to $\beta$ variations.

Using KVL in the base-emitter loop,

\[
V_{CC} - I_B R_B - V_{BE} = 0
\]

or,

\[
I_B = \frac{(V_{CC} - V_{BE})}{R_B}
\]

\[
I_C = \beta I_B = \beta \frac{(V_{CC} - V_{BE})}{R_B}
\]

Using KVL in the collector-emitter loop,

\[
V_{CC} - I_C R_C - V_{CE} = 0
\]

or,

\[
V_{CE} = V_{CC} - I_C R_C
\]

$Q(V_{CE}, I_C)$ is set
Improved Biasing: Resistive Divider

- Using a resistive divider to set $V_{BE}$, it is possible to produce an $I_C$ that is relatively insensitive to variations in $\beta$, if the base current is small.

Accounting for Base Current

- With a proper ratio of $R_1$ to $R_2$, $I_C$ can be relatively insensitive to $\beta$. However, its exponential dependence on $R_1//R_2$ makes it less useful.
Emitter Degeneration Biasing

- $R_E$ helps to absorb the change in $V_X$ so that $V_{BE}$ stays relatively constant.
- This bias technique is less sensitive to $\beta$ (if $I_1 \gg I_B$) and $V_{BE}$ variations.

Emitter Degeneration Biasing

Thevenin's Equivalent Circuit for the base-emitter loop

$$V_{th} = V_{CC} \frac{R_2}{(R_1 + R_2)}$$

$$R_{th} = R_1 || R_2 = \frac{R_1 R_2}{(R_1 + R_2)}$$

Base-Emitter Loop

$$V_{th} - I_B R_{th} - V_{BE} - (\beta + 1) I_B R_E = 0$$

or, $I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$

Collector-Emitter Loop

$$I_C = \beta I_B = \frac{\beta(V_{th} - V_{BE})}{R_{th} + (\beta + 1) R_E}$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = V_{CC} - I_C R_C - (I_C + I_B) R_E$$
Emitter Degeneration Biasing

**Bias Stabilization**

\[
I_C = \frac{\beta(V_{th} - V_{BE})}{R_{Th} + (\beta + 1)R_E}
\]

\[
V_{th} = V_{CC} \frac{R_2}{(R_1 + R_2)}
\]

If \(R_m < (\beta + 1)R_E\), then

\[
I_C \approx \frac{V_{Th} - V_{BE}}{R_E}
\]

So, \(I_C\) is independent of \(\beta\)

Emitter Degeneration Biasing

- \(R_E\) helps to absorb the change in \(V_X\) so that \(V_{BE}\) stays relatively constant.
- This bias technique is less sensitive to \(\beta\) (if \(I_1 >> I_B\)) and \(V_{BE}\) variations.

\[
I^* = \frac{V_{RE}}{V_{EC}}
\]

Small Enough to Avoid Saturation

\(V_{RE} = V_X - V_{BE}\)

\[V_{RE} >> \text{Variations in } V_X \text{ and } V_{BE}\]
Bias Circuit Design Procedure

1. Choose a value of \( I_C \) to provide the desired small-signal model parameters: \( g_m, r_o, \text{ etc.} \)
   \[
   s_m = \frac{I_C}{V_{BE}} ; \quad r_o = \frac{P}{5} \]

2. Considering the variations in \( R_1, R_2, \) and \( V_{BE}, \) choose a value for \( V_{RE}. \)
   \[
   V_{BE} \approx \frac{I_C}{R_E} \quad \text{e.g., } 200 \mu V \Rightarrow R_E \]

3. With \( V_{RE} \) chosen, and \( V_{BE} \) calculated, \( V_x \) can be determined.
   \[
   V_{BE} = V_T \ln \left( \frac{I_C}{I_s} \right) \quad V_x = V_{RE} + V_{BE} \]

4. Select \( R_1 \) and \( R_2 \) to provide \( V_x. \)
   \[ V_y = \frac{R_B}{R_1 + R_2} V_{CC} \]
   and \( I_1 \gg I_B, \) choose \( R_C \) to guarantee active mode operation.

Self-Biasing Technique

- This bias technique utilizes the collector voltage to provide the necessary \( V_x \) and \( I_B. \)
- One important characteristic of this approach is that the collector has a higher potential than the base, thus guaranteeing active-mode operation of the BJT.

\[
V_{BE} = V_T \ln \left( \frac{I_C}{I_s} \right) \\
V_y = V_{CC} - I_C R_C \quad (1) \\
V_y = V_{BE} + \frac{I_B R_B}{P} \quad (2) \\
I_C = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{\beta}} \approx \frac{V_{CC} - V_{BE}}{R_C} 
\]
Self-Biasing Design Guidelines

(1) \( R_C >> \frac{R_B}{\beta} \)

(2) \( \Delta V_{BE} << V_{CC} - V_{BE} \)

(1) provides insensitivity to \( \beta \).

(2) provides insensitivity to variation in \( V_{BE} \).

Emitter and Collector Feedback Bias
**Emitter and Collector Feedback Bias**

Applying KVL

or, \( V_{CC} - (I_C + I_B)R_C - I_B R_B - V_{BE} - (\beta + 1)I_B R_E = 0 \)

or, \( V_{CC} - (\beta I_B + I_B)R_C - I_B R_B - V_{BE} - (\beta + 1)I_B R_E = 0 \)

or, \( V_{CC} - (R_B + (\beta + 1)(R_C + R_E))I_B - V_{BE} = 0 \)

\[
I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)(R_C + R_E)}
\]

\[
V_{CE} = V_{CC} - (I_C + I_B)(R_C + R_E)
\]

---

**Emitter and Collector Feedback Bias**

\[
I_C = \frac{(V_{CC} - V_{BE})\beta}{R_B + (\beta + 1)(R_C + R_E)}
\]

\[
V_{CE} = V_{CC} - (I_C + I_B)(R_C + R_E)
\]

**Bias Stabilization**

If \( R_B \ll (\beta + 1)(R_C + R_E) \), then

or, \( I_C \approx \frac{V_{CC} - V_{BE}}{R_C + R_E} \)

So, \( I_C \) is independent of \( \beta \)
Summary of Biasing Techniques

Transistor as an Amplifier (ac in active region)
PNP BJT Biasing Techniques

- The same principles that apply to NPN BJT biasing also apply to PNP BJT biasing, with only voltage and current polarity modifications.