The BJT

(Bipolar Junction Transistor)

N-P-N Bipolar Junction Transistor

Figure 13.1 The n-p-n BJT.
N-P-N Bipolar Junction Transistor

- In normal operation, B-E junction is biased in forward and B-C junction is biased in reverse.

- Emitter current $i_E$ is given by Shockley’s equation:

$$i_E = I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]$$

The KCL requires that $i_E = i_C + i_B$

- Introducing the parameter $\alpha = i_C/i_E$ we can write:

$$i_C = \alpha I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]$$

and:

$$i_B = (1 - \alpha)i_E \quad i_B = (1 - \alpha)I_{ES} \left[ \exp \left( \frac{V_{BE}}{V_T} \right) - 1 \right]$$
N-P-N Bipolar Junction Transistor

- Defining the parameter $\beta = \frac{i_C}{i_B} = \alpha/(1-\alpha)$, we have: $i_C = \beta i_B$

![Diagram of N-P-N Bipolar Junction Transistor]

**Figure 13.3** Only a small fraction of the emitter current flows into the base (provided that the collector-base junction is reverse biased and the base-emitter junction is forward biased).

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Common-Emitter Characteristics

![Diagram of Common-Emitter Circuit]

**Figure 13.4** Common-emitter circuit configuration for the $npn$ BJT.
Common-Emitter Characteristics

Figure 13.5 Common-emitter characteristics of a typical npn BJT.

P-N-P Device

All equations are the same as for p-n-p device if we reverse the polarity of $v_{BE}$ and $v_{BC}$.

Figure 13.13 The pnp BJT.
**BJT: Regions of Operation**

(a) Output characteristic

(b) Input characteristic

Figure 13.17 Regions of operation on the characteristics of an n-p-n BJT.

**Large-Signal Models**

- Normal Active Region: \( B-E \) - \( \text{fwd} \), \( B-C \) - \( \text{rev} \).
**Large-Signal Models**

- **Saturation Region:** $\text{B-E - fwd, B-C - fwd}$

- **Cut-off Region:** $\text{B-E - rev., B-C - rev.}$
DC Analysis of BJT Circuits

![Figure 13.18 Bias circuit of Examples 13.4 and 13.5.](image)

DC Analysis of BJT Circuits

![Figure showing original circuit and equivalent circuit with separate voltage sources](image)
**DC Analysis of BJT Circuits**

(c) Circuit using Thévenin equivalent in place of $V_{CC}$, $R_B$, and $R_C$

(d) Equivalent to part (c) with active-region transistor model

KVL in a B-E loop gives:

$$V_B = I_B R_B + V_{BE} + I_E R_E$$

But $I_E = (\beta+1)I_B$, so:

$$V_B = I_B R_B + V_{BE} + (\beta+1)I_B R_E$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (\beta+1)R_E}$$
\[ i_B(t) = I_{BQ} + i_b(t) \]

\[ v_{BE}(t) = V_{BEQ} + v_{be}(t) \]

\( i_b(t) \) denotes the signal current flowing into the base, \( I_{BQ} \) is the dc current that flows when the signal is absent, and \( i_B(t) \) is the total base current. Similar notation is used for the other currents and voltages.

**BJT: Small-Signal Model (hybrid-\( \pi \))**

There are three mathematically identical models with different topology. Model 1 (with transconductance \( g_m \)):
There are three mathematically identical models with different topology. Model 2 (with CCCS $\beta_i b$):

![Diagram of BJT Small-Signal Model Model 2]

Model 3 (with emitter resistance $r_e$):

![Diagram of BJT Small-Signal Model Model 3]
BJT: Small-Signal Model (hybrid-π)

The values of the basic elements of the these models depend on the BJT parameters and the operating point.

\[ g_m = \frac{I_{CQ}}{V_T} \quad r_z = \frac{\beta}{g_m} \quad r_e = \frac{\alpha}{g_m} \quad r_o = \frac{V_A}{I_{CQ}} \]

Where:
- \( I_{CQ} \) – quiescent collector current
- \( V_T \) – thermal voltage (≈ 26 mV)
- \( V_A \) – Early voltage (≈ 100 V)
- \( \beta \) – transistor’s current gain
- \( \alpha = \beta / (\beta + 1) \)

Basic BJT Amplifiers

Common Emitter

\[ R_g = R_1 \parallel R_2 = \frac{R_1R_2}{R_1 + R_2} \]
Basic BJT Amplifiers
Common Emitter

Small-signal mid-band equivalent circuit:

Network functions:

\[ A_v = \frac{v_o}{v_i} = -\frac{g_m}{G_C + g_e + G_L} \]
\[ Z_{in} = \frac{1}{G_B + g_e} \]
\[ Z_{out} = \frac{1}{G_C + g_o} \]
Basic BJT Amplifiers
Common Collector (Emitter Follower)

Small-signal mid-band equivalent circuit:

Network functions:

\[ Z_{in} = \frac{1}{G_B + g_s (1 - A_v)} = \frac{1}{G_B} \]

\[ Z_{out} = \frac{1}{G_Z + g_m + g_v + G_E + g_o + G_l} \approx 1 \]

\[ A_v = \frac{v_o}{v_i} = \frac{g_m + g_v}{g_m + g_v + G_E + g_o + G_l} \approx 1 \]

Basic BJT Amplifiers
Common Base

Common Base Amplifier
Basic BJT Amplifiers
Common Base

Small-signal mid-band equivalent circuit:

\[ A_f = \frac{v_o}{v_i} = \frac{g_m + g_o}{G_C + G_e + G_L} \quad Z_{iv} = \frac{1}{G_e + g_m (1 - A_f) - g_m} \]