The ideal diode

Diode circuit symbol

\[ i-v \text{ characteristic} \quad \text{reverse bias} \quad \text{forward bias} \]

Real Diode

\[ i-v \text{ characteristic given by } i = I_s \left( e^{v/nV_{th}} - 1 \right) \text{ where} \]

\[ V_{th} = \frac{kT}{q} = 25 \text{ mV at room temperature} \]

Constant Voltage Drop Model for Diode

A typical value of \( V_{D0} \) is 0.7 V

Bipolar Junction Transistor (BJT)

Circuit Symbols

Voltage polarities and current flow in the active mode

(a) npn transistor, (b) pnp transistor.
Summary of BJT Current-Voltage Relationships in the Active Mode

\[ i_C = I_e \frac{v_{BE}}{v_{th}} \] (npn)

\[ i_C = I_e \frac{v_{CB}}{v_{th}} \] (pnp)

\[ V_{th} = \frac{kT}{q} = 25 \text{ mV at room temperature} \]

\[ i_E = i_C + i_B \]

\[ i_B = \frac{i_C}{\beta} = \frac{i_E}{\beta + 1} = (1 - \alpha) i_E \]

\[ i_C = \alpha i_E = \beta i_B \]

\[ i_E = \frac{i_C}{\alpha} = (\beta + 1) i_B \]

\[ \alpha = \frac{\beta}{\beta + 1}, \quad \beta = \frac{\alpha}{1 - \alpha}, \quad 0 < \alpha < 1 \]

Conditions and Models for the Operation of the BJT in Various Modes

**NPN**

- **Cutoff**
  - EBJ: Reverse Biased
  - CBJ: Reverse Biased

- **Active**
  - EBJ: Forward Biased
  - CBJ: Reverse Biased

**PNP**

- **Cutoff**
  - EBJ: Reverse Biased
  - CBJ: Reverse Biased

- **Active**
  - EBJ: Forward Biased
  - CBJ: Reverse Biased

- **Saturation**
  - EBJ: Forward Biased
  - CBJ: Forward Biased
Small-signal Parameters and Equivalent Circuit Models

\[ g_m = \frac{I_c}{V_{th}} \]

\[ r_{\pi} = \frac{\beta}{g_m} \Rightarrow r_{\pi} \gg \frac{1}{g_m} \]

\[ V_{th} = \frac{kT}{q} = 25 \text{ mV at room temperature} \]

\[ r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m} \]

Two versions of the simplified hybrid-\( \pi \) model for the small-signal operation of the BJT. The equivalent circuit in (a) represents the BJT as a voltage-controlled current source, and that in (b) represents the BJT as a current-controlled current source.

Amplifier Parameters and their Measurement

**R_i**

\[ R_i = \frac{V_i}{i_i} \]

**G_m and A_i**

\[ G_m = \frac{i_o}{v_i} \]

\[ A_i = \frac{i_o}{i_i} = \frac{v_o}{v_i} = i_i = G_m R_i \]

**R_o**

\[ R_o = \frac{V_x}{i_x} \]

**A_v**

\[ A_v = \frac{v_o}{v_i} = -G_m R_o \]
## BJT Amplifier Configurations

<table>
<thead>
<tr>
<th>Amplifier Type</th>
<th>Transistor Type</th>
<th>$R_i$</th>
<th>$R_o$</th>
<th>$A_v$</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>NPN</td>
<td>PNP</td>
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<tr>
<td>Common Emitter</td>
<td>$V_{CC}$</td>
<td>$V_{CC}$</td>
<td>$r_\pi$</td>
<td>$R_C$</td>
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<tr>
<td></td>
<td>$R_C$</td>
<td>$R_C$</td>
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<td>In</td>
<td>In</td>
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<tr>
<td></td>
<td>-$V_{EE}$</td>
<td>-$V_{EE}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Base</td>
<td>$V_{CC}$</td>
<td>$V_{CC}$</td>
<td>$r_v \approx \frac{1}{g_m}$</td>
<td>$R_C$</td>
</tr>
<tr>
<td></td>
<td>$R_C$</td>
<td>$R_C$</td>
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<tr>
<td></td>
<td>$V_{bias}$</td>
<td>$V_{bias}$</td>
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<tr>
<td></td>
<td>-$V_{EE}$</td>
<td>-$V_{EE}$</td>
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</tr>
<tr>
<td>Common Collector</td>
<td>$V_{CC}$</td>
<td>$V_{CC}$</td>
<td>$r_\pi + (\beta + 1) R_L$</td>
<td>$R_L \parallel r_v \approx R_L \parallel \frac{1}{g_m}$</td>
</tr>
<tr>
<td>(Emitter Follower)</td>
<td>$R_C$</td>
<td>$R_C$</td>
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<td></td>
<td>In</td>
<td>In</td>
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<tr>
<td></td>
<td>-$V_{EE}$</td>
<td>-$V_{EE}$</td>
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</tbody>
</table>
**MOSFET (MOS Field Effect Transistor)**

Cross-section of an NMOS transistor.

The drain current $i_D$ versus the drain-to-source voltage $V_{DS}$ for an NMOS transistor operated with $V_{GS} > V_t$.

---

**Equations for NMOSFET:**

$$i_D = \begin{cases} 
0 & \text{cutoff} \\
\frac{k}{2} \frac{W}{L} \left[ (V_{GS} - V_t) V_{DS} - \frac{V_{DS}^2}{2} \right] & \text{linear, nonsaturation} \\
\frac{k}{2} \frac{W}{L} (V_{GS} - V_t)^2 & \text{saturation}
\end{cases}$$

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Voltage polarities and current flow in the active mode
(a) NMOS transistor, (b) PMOS transistor.