Electronics I
EENG 3510

Lecture 19

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### 6.1 Device Structure and Physical Operation

#### 6.1.1 Simplified Structure and Modes of Operation (cont.)

BJT Modes of Operation

<table>
<thead>
<tr>
<th>Mode</th>
<th>EBJ</th>
<th>CBJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutoff</td>
<td>Reverse</td>
<td>Reverse</td>
</tr>
<tr>
<td>Active</td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>Reverse Active</td>
<td>Reverse</td>
<td>Forward</td>
</tr>
<tr>
<td>Saturation</td>
<td>Forward</td>
<td>Forward</td>
</tr>
</tbody>
</table>

Note: The symbol for Reverse Active indicates that the Collector–base junction (CBJ) is reverse biased with a value greater than 0.5 V.
6.1 Device Structure and Physical Operation

6.1.2 Operation of the *nnp* Transistor in the Active Mode

- **The Collector Current:**
  \[ i_C = I_S e^{\frac{v_{BE}}{V_T}} \]

- **The Base Current:**
  \[ i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{\frac{v_{BE}}{V_T}} \]

- **The Emitter Current:**
  \[ i_E = \frac{\beta + 1}{\beta} i_C = \frac{\beta + 1}{\beta} I_S e^{\frac{v_{BE}}{V_T}} = \left(\frac{I_S}{\alpha}\right) e^{\frac{v_{BE}}{V_T}} \]
6.2 Current-Voltage Characteristics

6.2.1 Circuit Symbols and Conventions

- **npn** or **pnp**: indicated by the direction of the arrowhead on the emitter
- **Drawing convention**: currents flow from top to bottom

**Figure** Circuit symbols for BJTs.

**Figure** Voltage polarities and current flow in transistors biased in the active mode.
6.2 Current-Voltage Characteristics

6.2.3 Dependence of $i_C$ on the Collector Voltage – The Early Effect

Figure (a) Conceptual circuit for measuring the $i_C - V_{CE}$ characteristics of the BJT. (b) The $i_C - V_{CE}$ characteristics of a practical BJT.
6.2 Current-Voltage Characteristics

6.2.3 Dependence of $i_c$ on the Collector Voltage – The Early Effect

Assuming $I_s$ remains constant and including new factor $(1 + V_{CE}/V_A)$ for $i_c$:

$$i_c = I_s e^{v_{BE}/V_T} \left(1 + \frac{V_{CE}}{V_A}\right)$$

Figure  Large-signal equivalent-circuit models of an npn BJT operating in the active mode in the common-emitter configuration.
6.3 BJT Circuit at DC

Cutoff

Active

Saturation
Example 6.4:

To determine the voltages at all nodes and the currents through all branches. Assume that the transistor $\beta$ is specified to be 100.

1. Assume active: $V_{BE} = 0.7V$, $V_E = 4 - 0.7 = 3.3 V$
2. $I_E = (3.3-0) / 3.3 = 1mA$
3. $I_C = \alpha I_E = (100/101)I_E \approx 0.99 mA$
4. $V_C = 10 - 0.99 \times 4.7 = 5.3 V > V_B + 0.5V$

1. Assume saturation: $V_{BE} = 0.7V$, $V_E = 4 - 0.7 = 3.3 V$
2. $I_E = (5.3-0) / 3.3 = 1mA$
3. $V_{CE} = 0.2 V$, $V_C = V_E + V_{CE} = 3.3 + 0.2 = 3.5 V$
4. $I_C = (10 - 3.5) / 4.7 \approx 1.38 mA$
5. $I_B = I_E - I_C < 0$
Example 6.6:

To determine the voltages at all nodes and the currents through all branches.

Cut Off

\[ R_C = 4.7 \text{ k}\Omega \]

\[ R_E = 3.3 \text{ k}\Omega \]

\[ V = 10\text{V} \]

\[ V = 0\text{V} \]
Example 6.8:

To determine the voltages at all nodes and the currents through all branches. Assume $\beta = 100$. 

\[ I_B = \frac{5 - 0.7}{100} = 0.043 \text{ mA} \]

\[ I_C = 100 \times 0.043 = 4.3 \text{ mA} \]

\[ V_C = 10 - 2 \times 4.3 = +1.4 \text{ V} \]

\[ I_E = 4.3 + 0.043 = 4.343 \text{ mA} \]