Lecture 17

Bipolar Junction Transistors (BJT): Part 1
Qualitative Understanding - How do they work?

Reading:
Pierret 10.1-10.6, 11.1
Bipolar Junction Transistor Fundamentals

Looks sort of like two diodes back to back

\[ \text{pnp mnemonic: } \text{“Pouring ‘N’ Pot”} \]

\[ \text{nnp mnemonic: } \text{“Not Pouring ‘N’”} \]

Voltage Nomenclature Standard \( V_{+} \)
Bipolar Junction Transistor Fundamentals

Emitter “emits” holes
Narrow Base controls number of holes emitted
Collector “collects” holes emitted by the emitter

Emitter “emits” electrons
Narrow Base controls number of electrons emitted
Collector “collects” electrons emitted by the emitter

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Bipolar Junction Transistor Fundamentals

\[ I_E = I_B + I_C \]

\[ V_{EB} + V_{BC} + V_{CE} = 0 \]
Bipolar Junction Transistor Fundamentals

Both the input and output share the base “in common”

Both the input and output share the emitter “in common”

Both the input and output share the Collector “in common”
### Bipolar Junction Transistor Fundamentals

<table>
<thead>
<tr>
<th>Biasing Mode</th>
<th>Biasing Polarity E–B Junction</th>
<th>Biasing Polarity C–B Junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>Forward</td>
<td>Forward</td>
</tr>
<tr>
<td>Active</td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>Inverted</td>
<td>Reverse</td>
<td>Forward</td>
</tr>
<tr>
<td>Cutoff</td>
<td>Reverse</td>
<td>Reverse</td>
</tr>
</tbody>
</table>

- **Active**: Is useful for amplifiers. Most common mode
- **Saturation**: Equivalent to an on state when transistor is used as a switch
- **Cutoff**: Equivalent to an off state when transistor is used as a switch
- **Inverted**: Rarely if ever used.
Bipolar Junction Transistor Fundamentals

Equilibrium

Cutoff

Saturation

Active (or Forward Active)
Bipolar Junction Transistor Fundamentals

• When there is no base current, almost no collector current flows
• When base current flows, a collector current can flow
• The device is then a current controlled current device

Operational modes can be defined based on base-emitter voltages and base-collector voltages.
Bipolar Junction Transistor Fundamentals: Electrostatics in Equilibrium

Emitter Doping > Base Doping > Collector Doping

Emitter is heavily doped

$W =$ width of the base quasi-neutral region

$W_B =$ Total Base width

$W_{EB} =$ Base-Emitter depletion width

$W_{CB} =$ Base-Collector depletion width

$W_{EB} < W_{CB}$

Note: This slide refers to a pnp transistor
Bipolar Junction Transistor Fundamentals

Equilibrium

Active Mode

Few electrons injected into the emitter

Many Holes injected into the base

Injected Holes diffuse through the base and are collected by the huge electric field at the collector

Narrow Base required to minimize recombination

Note: This slide refers to a pnp transistor
Neglecting recombination-generation means $I_{Cp} \approx I_{Ep}$

Since emitter is more heavily doped than the base, $I_{En} \ll I_{Ep}$

Since the base-collector junction is reverse biased, $I_{Cn} \ll I_{cp}$

$I_C \approx I_E$ and ($I_B = I_E - I_C$) is small compared to $I_C$ and $I_E$
Consider a pnp Transistor: A small electron base current (flowing into the emitter from the base) controls a larger hole current flowing from emitter to collector. Effectively, we can have the collector-emitter current controlled by the base-emitter current.

Note: This slide refers to a pnp transistor.
Bipolar Junction Transistor Fundamentals:
Performance Parameters

(1) \( \gamma = \frac{I_{Ep}}{I_E} = \frac{I_{Ep}}{I_{Ep} + I_{En}} \)

**Emitter Efficiency:** Characterizes how effective the large hole current is controlled by the small electron current. Unity is best, zero is worst.

(2) \( \alpha_T = \frac{I_{Cp}}{I_{Ep}} \)

**Base Transport Factor:** Characterizes how much of the injected hole current is lost to recombination in the base. Unity is best, zero is worst.

Note: This slide refers to a pnp transistor.
Bipolar Junction Transistor Fundamentals: Performance Parameters

Active Mode, Common Base Characteristics

$I_C$ = fraction of emitter current making it across the base + leakage current

$$I_C = \alpha_{dc} I_E + I_{CBO}$$  where $\alpha_{dc}$ is the common base DC current gain

Combining (1) and (2),

$$I_{Cp} = \alpha_T I_{Ep} = \gamma \alpha_T I_E$$

$$I_C = I_{Cp} + I_{Cn} = \alpha_T I_{Ep} + I_{Cn} = \gamma \alpha_T I_E + I_{Cn}$$

Thus comparing this to (3),

$$\alpha_{dc} = \gamma \alpha_T \quad \text{and} \quad I_{CBO} = I_{Cn}$$

Note: This slide refers to a pnp transistor

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Bipolar Junction Transistor Fundamentals: Performance Parameters

Active Mode, Common Emitter Characteristics

I_C = \text{multiple of the base current making it across the base + leakage current}

(4) \quad I_C = \beta_{dc} I_B + I_{CEo} \quad \text{where } \beta_{dc} \text{ is the common emitter DC current gain}

But using I_E = I_C + I_B in (2),

(5) \quad I_C = \alpha_{dc} (I_C + I_B) + I_{CBo}

and solving for I_C

(6) \quad I_C = \frac{\alpha_{dc}}{1 - \alpha_{dc}} I_B + \frac{I_{CBo}}{1 - \alpha_{dc}}

comparing (4) and (6)

\[
\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}} \quad \text{and} \quad I_{CEo} = \frac{I_{CBo}}{1 - \alpha_{dc}} \quad \text{and} \quad \beta_{dc} = \frac{I_C}{I_B}
\]

Note: This slide refers to a pnp transistor

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