NPN Bipolar Junction Transistor

• An npn BJT consists of a thin layer of p-type material between two layers of n-type material as shown in the figure.
• In most cases the base-emitter junction is forward biased and the base-collector junction is reverse biased (active region).

• The emitter is heavily doped compared with the base. Most of the current is due to electrons moving from the emitter.
• Base current consists of holes crossing from the base into the emitter and of holes that recombine with electrons in the base.
Common-Emitter Characteristics

- Input characteristic is similar to the forward bias characteristic of a pn junction.
- In the output characteristics, the collector current is independent of $V_{CE}$.

Common-emitter characteristics of a typical *n*pn BJT.

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Key Equations

\[ I_E = I_C + I_B \]

\[ I_E = I_{ES} \left( e^{\frac{V_{BE}}{V_T}} - 1 \right) \]

\[ \alpha = \frac{I_C}{I_E} \]

\[ \beta = \frac{I_C}{I_B} \]

- KCL
- Diode current
- Emitter injection efficiency
  - Typically near 1 (small \( I_B \))
- Current gain
  - Typically high (hundreds)
Secondary Effects

- Base-width Modulation
- Collector Breakdown
- Leakage Current
Base-width Modulation

- Collector current is not $V_{CE}$ independent
  - Base width decreases (quicker sweeping of electrons to collector)
- The straight line extension of collector current curves all meet at a point on the negative $V_{CE}$ axis. The voltage amplitude at the intersection is called the Early voltage.

Common-emitter characteristics displaying exaggerated secondary effects.
Collector Breakdown

- There are two main reasons for collector breakdown
  - Avalanche Breakdown
    Reverse bias high enough to breakdown the BC pn junction
    (refer back to Figure 3.1b)
  - Punchthrough
    Neutral base width reduces down to 0
Leakage Current

• Negative base current even when the transistor is off
  – Due to reverse leakage current of the base-collector junction
• Leakage also occurs at $I_B = 0$ for the same reason
  – Leakage is amplified as it passes from collector to emitter (see slide 8)

(a) Input characteristics

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Analysis of common emitter amplifier

- Input: $v_{in}$ (AC signal)
- Output: $v_{CE}$

$$V_{BB} + v_{in} - i_B R_B - v_{BE} = 0$$

$$V_{CC} - i_C R_C - v_{CE} = 0$$
Example 4.2: load-line analysis

\[ i_B = -\frac{1}{R_B} v_{BE} + \frac{V_{BB} + v_{in}}{R_B} \]

Load line (slope = \(-1/R_B\))

Range of \( I_B \)

Range of \( v_{BE} \) (~ constant)

Load-line analysis for Example 4.2.
Load-line analysis for Example 4.2.

\[ i_C = -\frac{1}{R_C} v_{CE} + \frac{V_{CC}}{R_C} \]

Range of \( I_B \) (from input curves)

Range of \( V_{CE} \) (output)
Input-output waveforms

Voltage waveforms for the amplifier of Example 4.2.

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Distortion

- Distortion occurs in BJT amplifiers due to nonlinearity of the input characteristic and non-uniform spacing of the output characteristic.

Output of the amplifier of Example 4.2 for $v_{in}(t) = 1.2 \sin(2000\pi t)$ showing gross distortion.

If $v_{in} = -1.2$, $I_B = 1 \mu A$
If $v_{in} = -1.2$, $I_B$ = huge
(use load line on slide 12)
Clipping occurs if the BJT swing reaches saturation or cutoff.

Amplification occurs in the active region. Clipping occurs when the instantaneous operating point enters saturation or cutoff. In saturation, $v_{CE} < 0.2 \text{ V}$. 

$I_B = 1 \mu \text{A}$

$I_B = \text{huge}$
PNP BJT

- In active region $V_{BE}$ is negative (so that the BE junction forward biases)

Emitter at top (not collector) (done so that circuit voltages can stay positive)

(a) Physical structure

(b) Circuit symbol with reference directions for currents

The $pnp$ BJT (reversed from npn)
Common Emitter Characteristic for PNP

• Note that the input and output characteristics are the same as NPN except the voltage scale is now negative.

Common-emitter characteristics for a pnp BJT.

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