

VE320 Intro to Semiconductor Devices

Chapter 12. The Bipolar Transistor (BJT)

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August 1, 2022

- 1 Objectives
- 2 The BJT Working Principle
 - BJT Structure
 - Basic Principle of Operation
 - Operation Mode
 - Minority Carrier Distribution
- 3 Non-ideal Effects
 - Early Effect

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Objective

1. Learn the working principle for BJT
 - 1.1 BJT structure
 - 1.2 Basic principle of operation
 - 1.3 Different operation modes
 - 1.4 Minority carrier distribution
2. Learn the non-ideal effect: early effect

1 Objectives

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BJT Structure

1. BJT has three doped regions and two pn junction
2. Three terminal connections: emitter, base, and collector

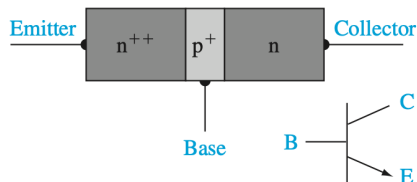


Figure: npn BJT

BJT Structure

3. The (++) and (+) notation indicates the relative magnitudes of the impurity doping concentrations
4. The width of the base region is small compared to the minority carrier diffusion length

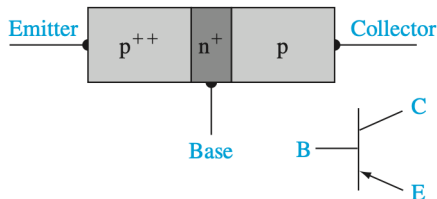


Figure: pnp BJT

Basic Principle of Operation

1. Typical impurity doping concentrations in the emitter, base, and collector may be on the order of 10^{19} cm^{-3} , 10^{17} cm^{-3} , and 10^{15} cm^{-3}

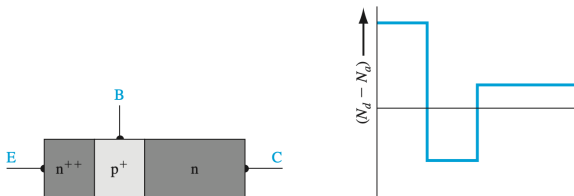


Figure: Idealized doping profile of a npn BJT

Basic Principle of Operation

2. In the normal bias configuration: the B-E pn junction is forward biased and the B-C pn junction is reversed biased (**forward-active** operation mode)
- **Question:** How electron moves in this mode?

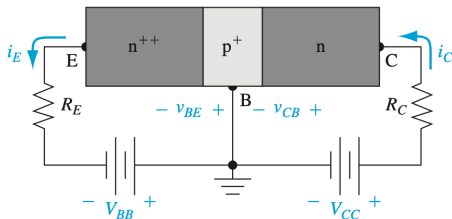
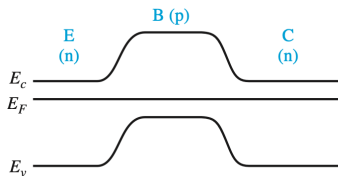


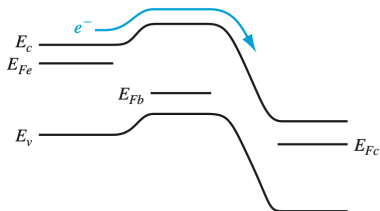
Figure: Biasing of an npn BJT in the forward-active mode

Basic Principle of Operation

3. Energy-band diagram of npn BJT:



Zero bias



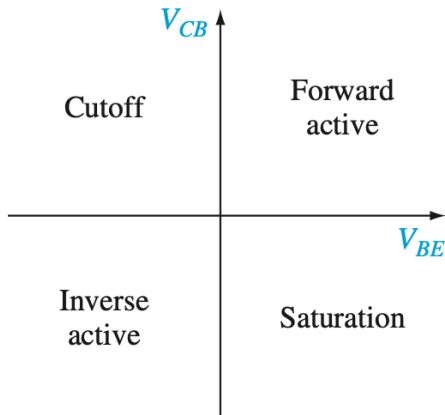
Forward active

Basic Principle of Operation

4. **Draw:** Energy-band diagram of pnp BJT:

Operation Mode

1. Cutoff: $V_{BE} \leq 0$, so $i_E = i_C = 0$
2. Forward-active: $V_{BE} > 0$, $V_{CB} > 0$, so $i_C = \beta i_B$
3. Saturation: $V_{BE} > 0$, $V_{CB} \leq 0$, both pn junction are forward biased, i_C doesn't depend on V_{BE}



Current-Voltage Characteristic

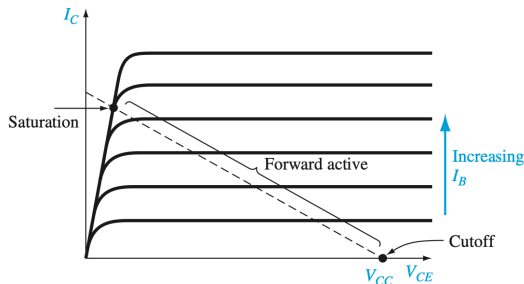


Figure: BJT common-emitter current-voltage characteristics

Minority Carrier Distribution

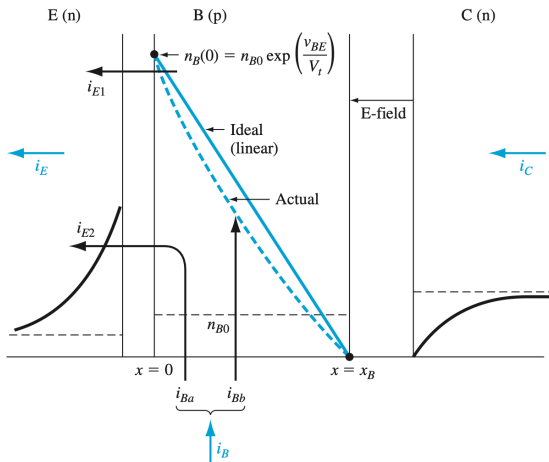


Figure: Minority carrier distributions and basic currents in a forward-biased npn BJT

Minority Carrier Distribution

1. Parameters:

$$\begin{cases} \alpha : & \text{common-base current gain } (\alpha \sim 1) \\ \beta : & \text{common-emitter current gain } (\beta \gg 1) \end{cases}$$

2. Collector current: i_C is controlled by v_{BE}

$$|J_C| = \frac{eD_B n_{B0}}{x_B} \exp\left(\frac{V_{BE}}{V_t}\right)$$

$$i_C = \frac{-eD_n A_{BE}}{x_B} n_{B0} \exp\left(\frac{V_{BE}}{V_t}\right) = I_s \exp\left(\frac{V_{BE}}{V_t}\right)$$

3. Emitter current: $\frac{i_C}{i_E} = \alpha$. $i_E = I_{SE} \exp\left(\frac{V_{BE}}{V_t}\right)$

4. Base current: $\frac{i_C}{i_B} = \beta$. $i_B \propto \exp\left(\frac{V_{BE}}{V_t}\right)$

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Early Effect

- Previous assumption: base width x_B is constant
- In reality: x_B changes with V_{CB} . The width of the space charge region extending into the base region varies with B–C voltage, i.e.,

$$V_{CB} \uparrow \Rightarrow \text{BC space charge region width} \uparrow \Rightarrow x_B \downarrow$$

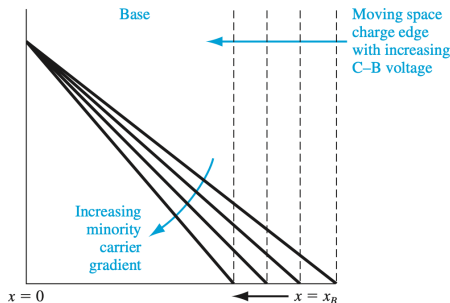


Figure: Change of x_B and minority carrier gradient as the B–C space charge width changes

Early Effect

1. Current-voltage characteristic: I_C changes with V_{CE}/V_{CB}
2. g_o : output conductance, r_o : output resistance:

$$\begin{cases} \frac{dI_C}{dV_{CE}} \equiv g_o = \frac{I_C}{V_{CE} + V_A} = \frac{1}{r_o} \\ I_C = g_o(V_{CE} + V_A) = \frac{1}{r_o}(V_{CE} + V_A) \end{cases}$$

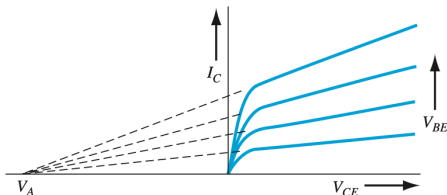


Figure: The collector current versus C-E voltage showing the Early effect and Early voltage.

Exercise

Early Effect

A uniformly doped silicon npn bipolar transistor at $T=300\text{ K}$ has parameters $N_E = 2 \times 10^{18}\text{cm}^{-3}$, $N_B = 2 \times 10^{16}\text{cm}^{-3}$, $N_C = 2 \times 10^{15}\text{cm}^{-3}$, $x_{B0} = 0.85\mu\text{m}$, and $D_B = 25\text{ m}^2/\text{s}$. Assume $x_{B0} \ll L_B$ and let $V_{BE} = 0.650\text{ V}$.

- (a) Determine the electron diffusion current density for $V_{CB} = 4\text{ V}$ and $V_{CB} = 12\text{ V}$.
- (b) Estimate the Early voltage.

Answer

End

- Thank you all for your tolerance and support this semester. We will all have a bright future! Good luck for everything!

