Vincent Maguire / BJT distilled

Structure / modes of operation

1. In **Active mode** transistor operates like an amplifier.
2. In **Saturation mode** transistor operates like a switch.
3. In **Cutoff mode** no current flows.

Active mode

In active mode the **Emitter-base** junction is forward biased ($V_{BE} > 0$) and the **collector-base** junction is reverse biased ($V_{CB} > 0$).

- A higher potential at the p-type vs the n-type causes a forward bias.
  - Current flows from the p-type to the n-type.
- A higher potential at the n-type vs the p-type causes a reverse bias.
  - Current flows from the n-type to the p-type.

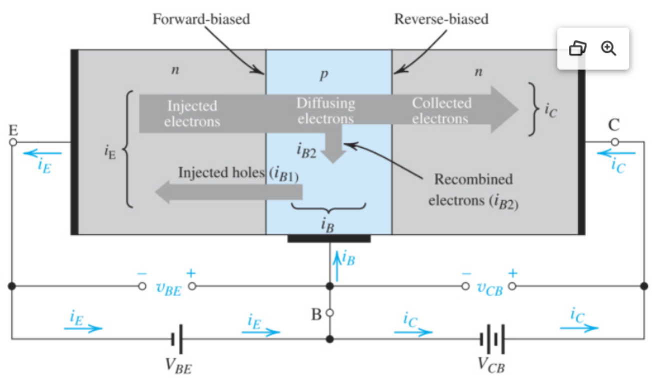

Figure 1: Active NPN structure

$$i_E \textbf{ is proportional to } e^{\frac{V_{BE}}{V_T}}$$

$$i_C = I_s e^{\frac{V_{BE}}{V_T}}$$

- i_C is independent of V_{CB}

$$i_B = \frac{i_c}{\beta} = \frac{I_S}{\beta} e^{\frac{V_{BE}}{V_T}}$$

- β is the **common-emitter current gain.**

$$i_E = i_C + i_B = \frac{\beta+1}{\beta} * i_C = \frac{\beta+1}{\beta} I_S e^{\frac{V_{BE}}{V_T}}$$

- α **is** $\frac{\beta}{\beta+1}$ or β **is** $\frac{\alpha}{1-\alpha}$ where α **is the common-base current gain**

In an NPN transistor, The CBJ has a much larger area than EBJ. The CB diode, D_C has a saturation current I_{SC} that is 10 - 100 times larger than I_{SE}. $I_{SE} = \frac{I_S}{\alpha} \approx I_S$

Saturation Mode

If the **Collector-base** junction V_{BC} is forward biased and the **Emitter-base** Junction V_{BE} is forward biased, the transistor enters saturation mode.

- For an *npn* transistor $V_{\mathbf{CB}} < -0.4$ or equivelently $V_{\mathbf{BC}} > 0.4$
- The ratio $\frac{i_c}{i_b} < \beta$

Know the difference:

- I_{SC} **is the base-collector leakage saturation current (A)**
- I_{SE} **is the base emitter leakage saturation current (A)**
- I_S **is the transport saturation current (A)**

The equations...

1. $$i_c = I_s e^{\frac{V_{BE}}{V_T}} - I_{SC} e^{\frac{V_{BC}}{V_T}}$$

2. $$i_B = (\frac{I_S}{\beta}) e^{\frac{V_{BE}}{V_T}} + I_{SC} e^{\frac{V_{BC}}{V_T}}$$

...can be used to find the ratio $\frac{i_C}{i_B}$ for a saturated transistor.
The ratio decreases as V_{BC} is increased and the transistor is driven deeper into saturation, the ratio $\frac{i_C}{i_B}$ is known as $\boldsymbol{\beta_{forced}}$ because it can be set to any desired value lower than β by adjusting V_{BC}.

$$V_{CEsat} = V_{BE} - V_{BC}$$

For edge if saturation $V_{CEsat} = 0.3$V, for deep in saturation $V_{CEsat} = 0.2$V

V_{CE}, Where is i_c zero?

Using the equation $i_c = I_s e^{\frac{V_{BE}}{V_T}} - I_{SC} e^{\frac{V_{BC}}{V_T}}$ we understand that i_C reaches zero at $V_{CE} = V_T ln(\frac{I_{SC}}{I_S})$. This expression is derived algebraically from the previous.

PNP Transistor

In active mode the **Emitter-Base junction** is forward biased ($V_{EB} > 0$) and the **Collector-Base junction** is negatively biased ($V_{BC} > 0$)

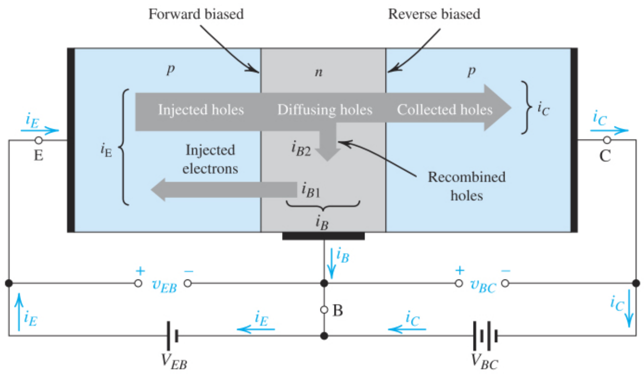

Figure 2: PNP in active reigon

The *PNP* device is analogous to the *NPN* device with the exception that V_{BE} is replaced with V_{EB}