University of Glasgow

UESTC3002: Electronic Devices

Lecture 07
The Bipolar Transistor

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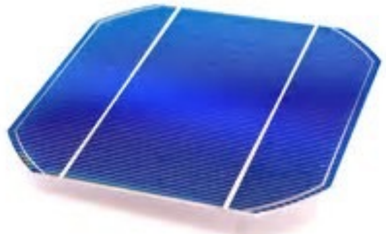
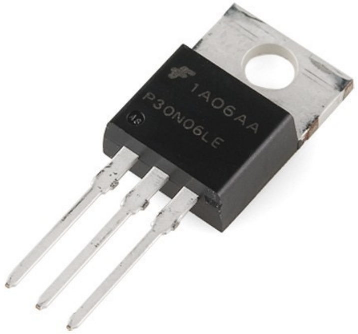
Thanks to Prof R Ghannam

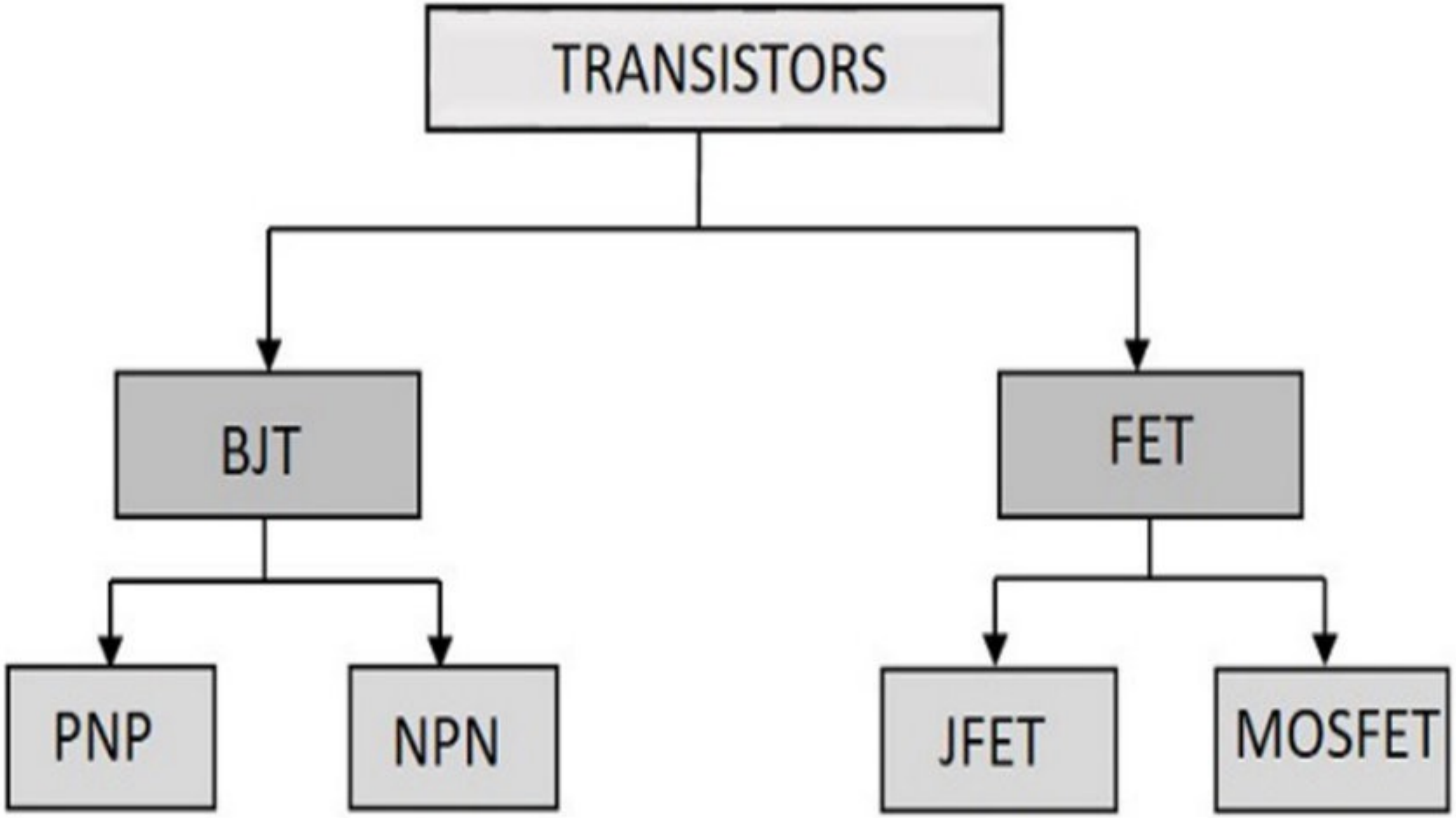
Block 3 Lectures

Electronic Devices





Types of Transistors



BJT – Bipolar Junction Transistor
JFET – Junction FET

FET - Field Effect Transistor
MOSFET – Metal Oxide Semiconductor FET

Bipolar Junction Transistor

- Invention of BJT in 1948 at Bell Labs led to electronics changing the way we work, play, and live.

- BJTs can be found in several electronic devices such mobile phones, radios, etc.

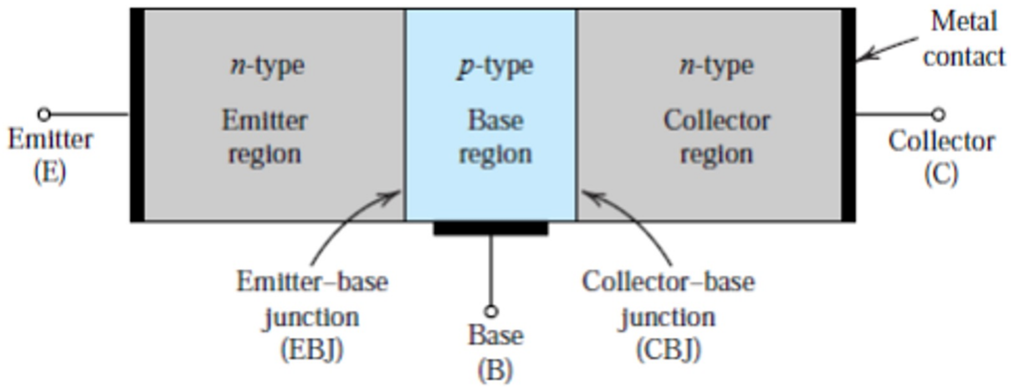
- BJTs are mainly used for amplification and switching.

Bipolar Junction Transistor

- BJTs can be thought of as two diodes (p-n junctions) sharing a common region.
- Thus, there are two possible configurations with three terminals (emitter, base and collector)
    - npn BJT
    - pnp BJT

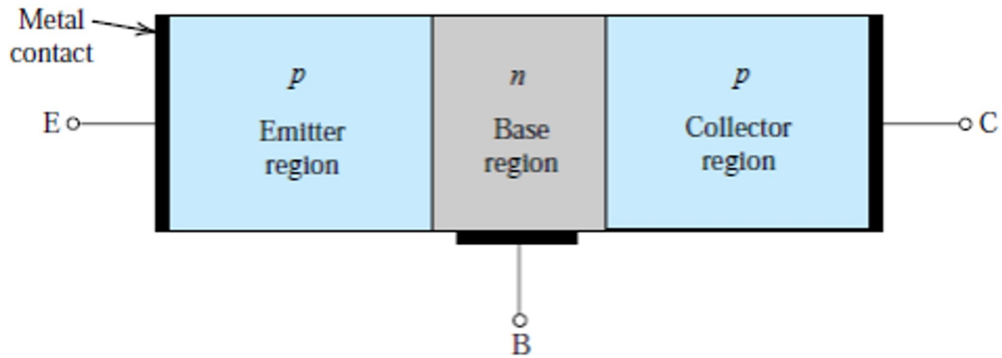
- In a ***npn*** transistor, the BJT consists of three semiconductor regions: the emitter region (*n* type), the base region (*p* type), and the collector region (*n* type).

npn BJT

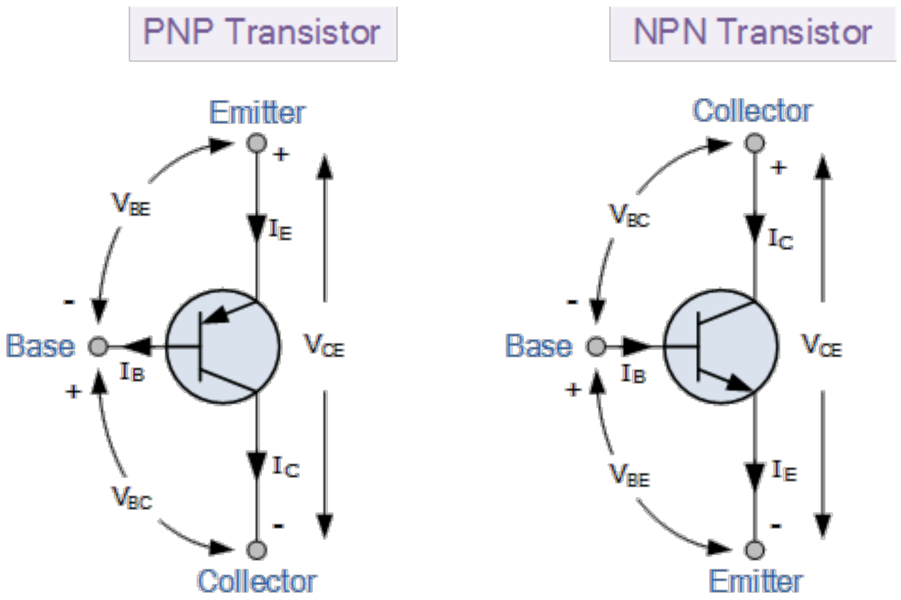


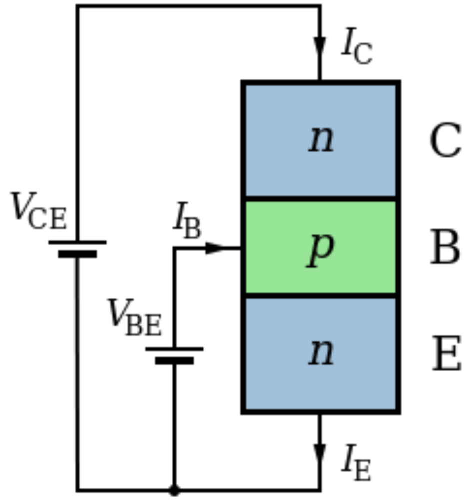
- *A* ***pnp*** transistor has a *p*-type emitter, an *n*-type base, and a *p*-type collector.

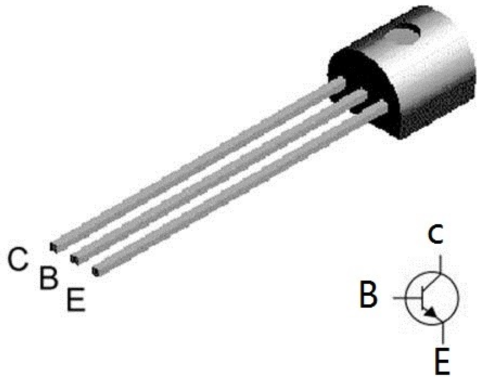
pnp BJT

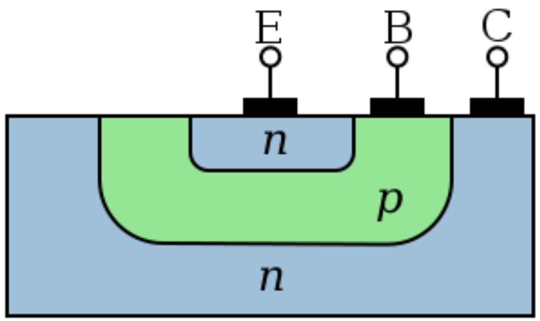


BJT Modes of Operation

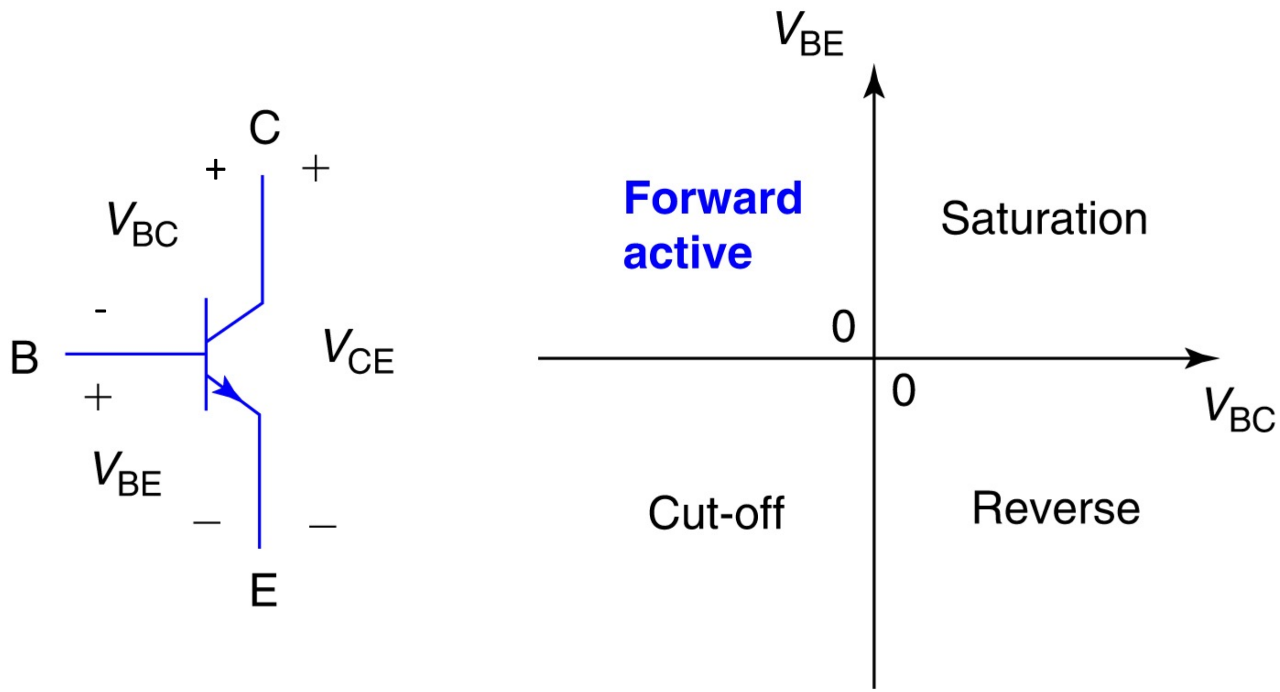






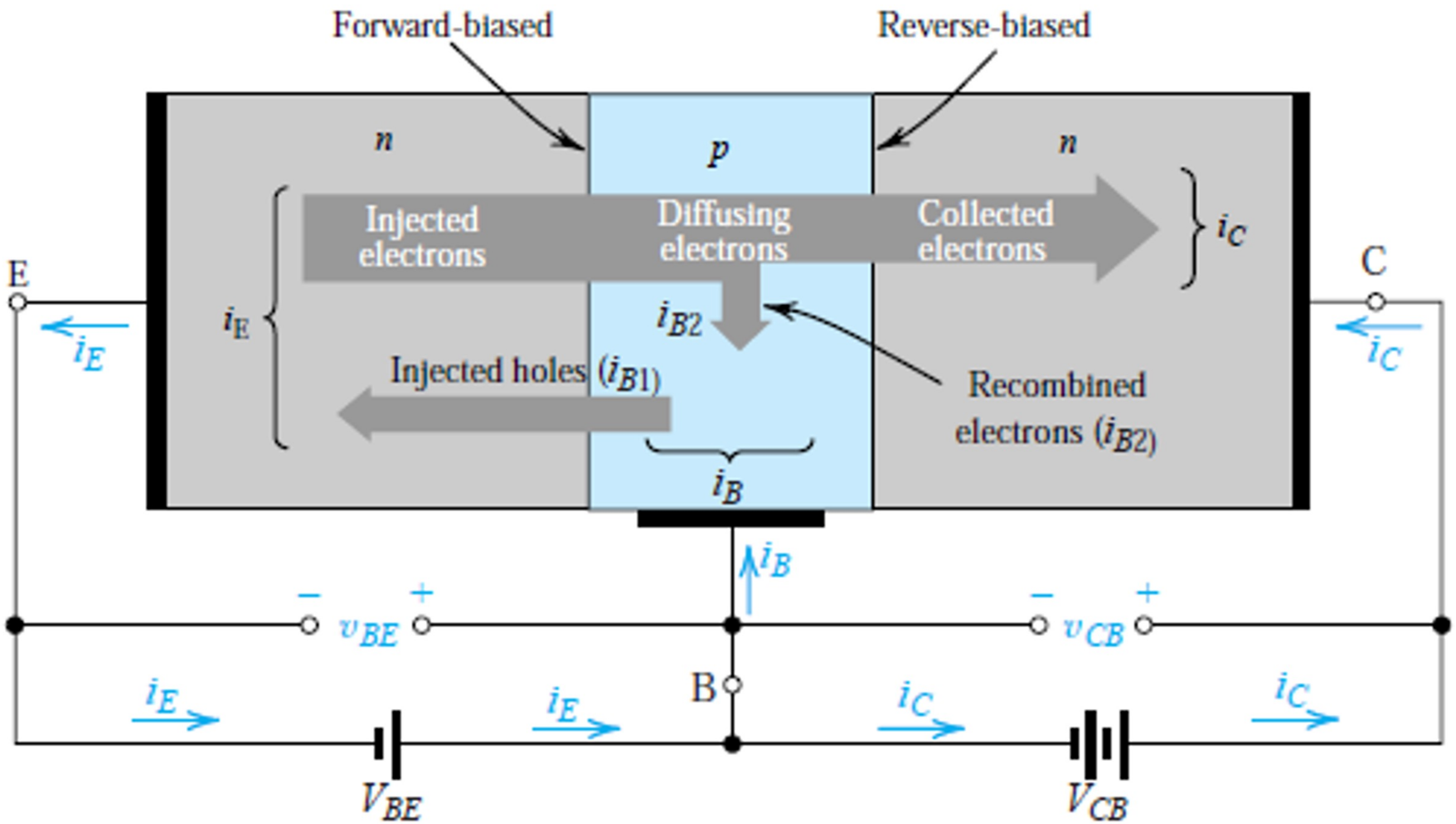


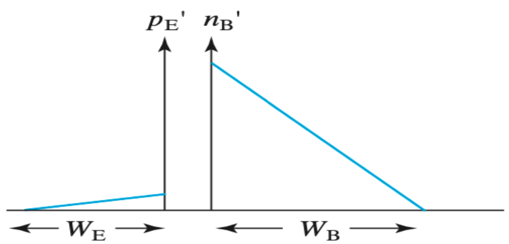
BJT Modes of Operation



Forward Active Region

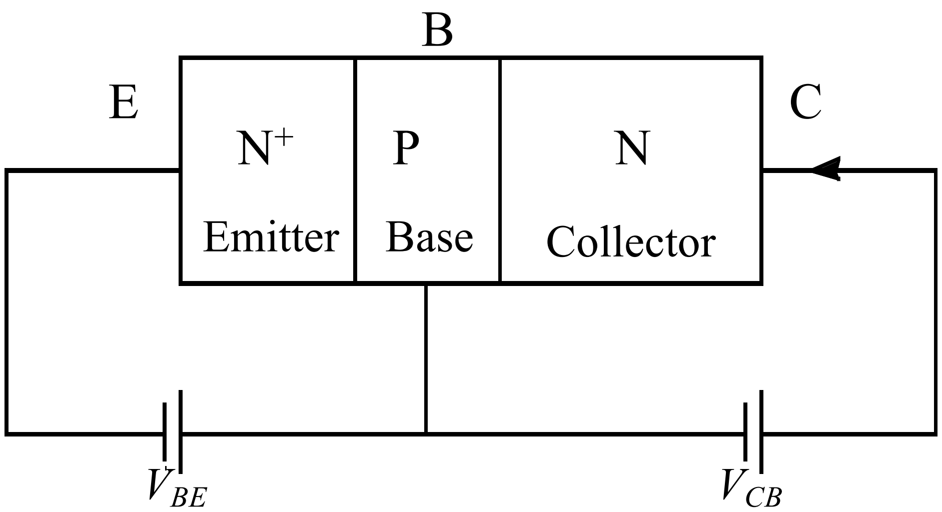
Active Mode npn-BJT

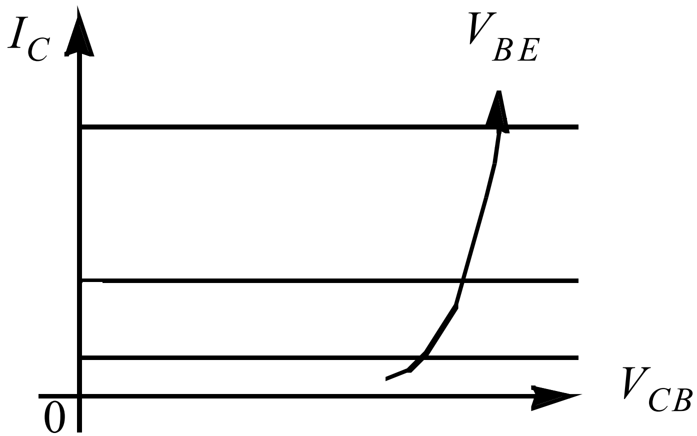




Minority carriers' diffusion

Active Mode npn-BJT





I_C is an exponential function of forward V_{BE} and independent of reverse V_{CB}.

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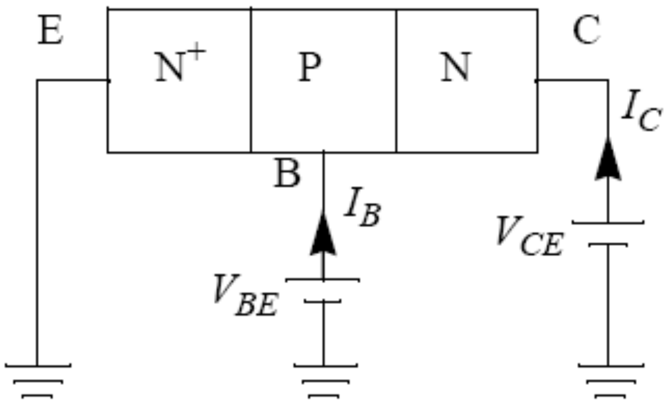
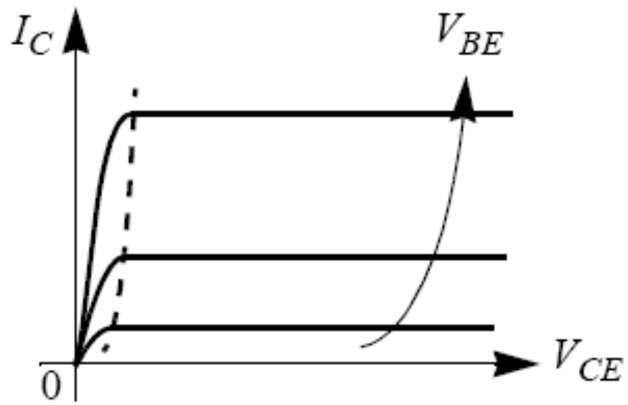
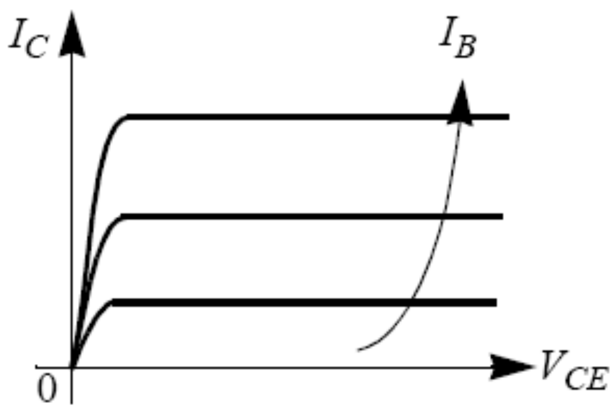
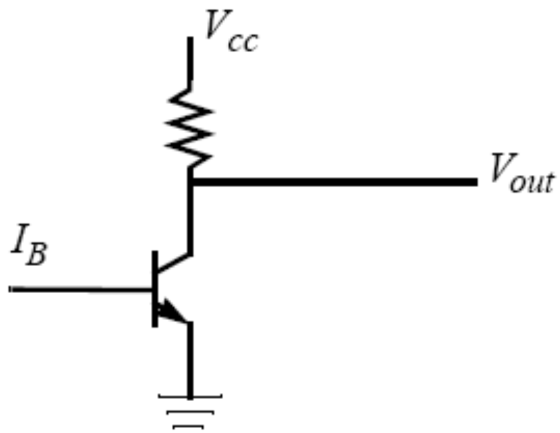
Common-Emitter Configuration









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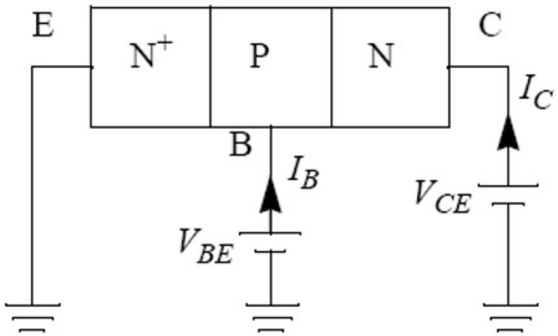
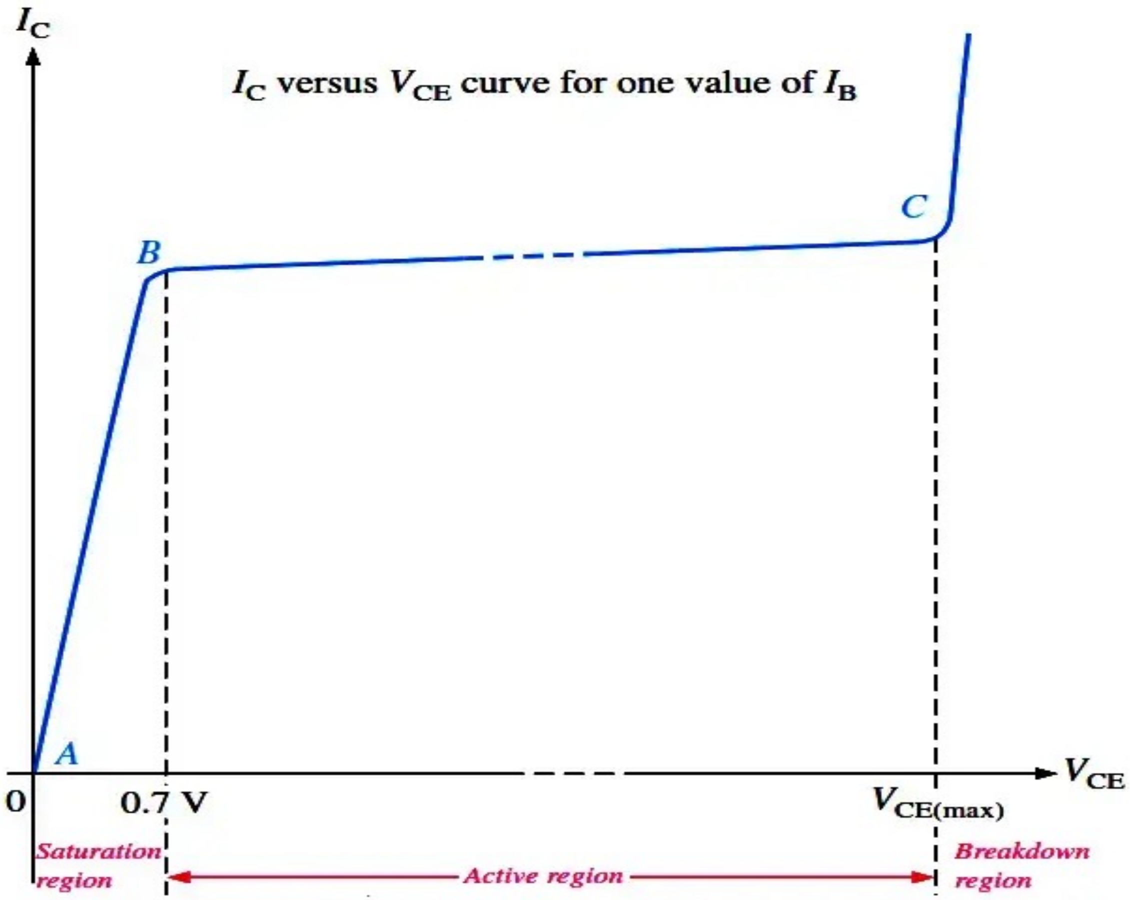
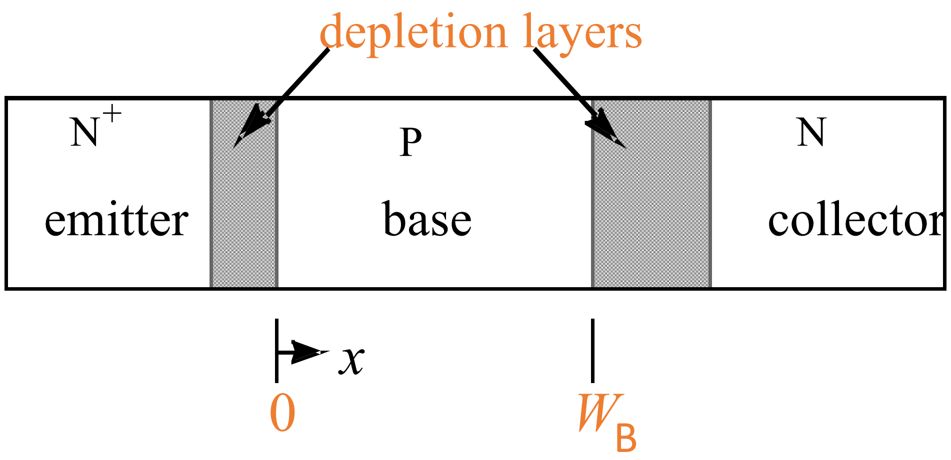
BJT Characteristic Curve – I_C vs V_{CE}





Collector Current



$$\boxed{I_C = I_S(e^{qV_{BE}/kT} - 1)}$$

$$= A_E q \frac{D_B}{W_B} \frac{n_{iB}^2}{N_B} (e^{qV_{BE}/kT} - 1)$$

D_B : base minority carrier (electron) diffusion constant

N_B : Base doping concentration

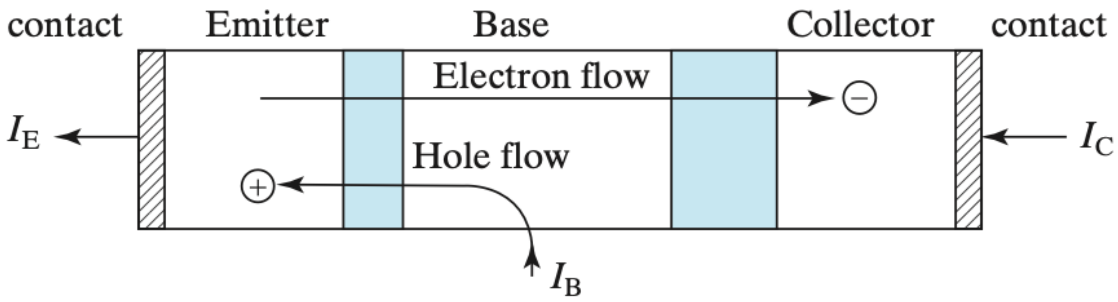
A_E : Surface Area of Emitter

W_B : Base width

n_{iB} : intrinsic carrier concentration of Base

Base Current

Some holes are injected from the P-type base into the N^+ emitter. The holes are provided by the base current, I_B .



For a uniform emitter,

$$I_B = A_E q \frac{D_E n_{iE}^2}{W_E N_E}(e^{qV_{BE}/kT} - 1)$$

Current Gain

Common-emitter current gain, β_F :

$$\boxed{\beta_F \equiv \frac{I_C}{I_B}}$$

Common-base current gain:

$$I_C = \alpha_F I_E$$

$$\alpha_F \equiv \frac{I_C}{I_E} = \frac{I_C}{I_B + I_C} = \frac{I_C / I_B}{1 + I_C / I_B} = \frac{\beta_F}{1 + \beta_F}$$

It can be shown that $\boxed{\beta_F = \dfrac{\alpha_F}{1 - \alpha_F}}$

$$\beta_F = \frac{G_E}{G_B} = \frac{D_B W_E N_E n_{iB}^2}{D_E W_B N_B n_{iE}^2}$$

How can β_F be maximized?

EXAMPLE: Current Gain

A BJT has I_C = 1 mA and I_B = 10 μA. What are I_E, β_F and α_F?

Solution:

$$I_E = I_C + I_B = 1\,\text{mA} + 10\,\mu\text{A} = 1.01\,\text{mA}$$

$$\beta_F = I_C / I_B = 1\,\text{mA} / 10\,\mu\text{A} = 100$$

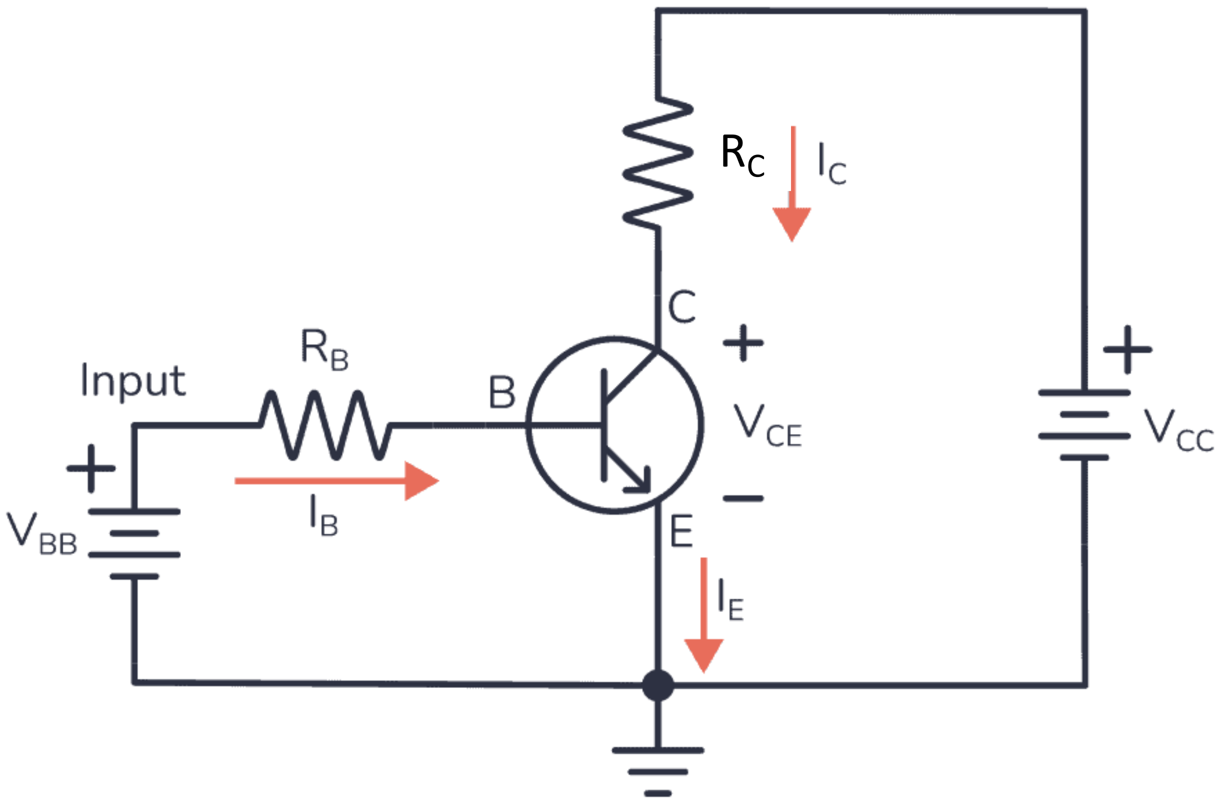
$$\alpha_F = I_C / I_E = 1\,\text{mA} / 1.01\,\text{mA} = 0.9901$$

We can confirm

$$\alpha_F = \frac{\beta_F}{1+\beta_F} \quad \text{and} \quad \beta_F = \frac{\alpha_F}{1-\alpha_F}$$

EXAMPLE: BJT Circuit

A BJT has R_C= 5 kΩ and R_B= 20 kΩ. Consider V_{CC}=12 V and β=70. What value of V_{BB} will be needed to bring the transistor to saturation?



BJT Power consumption

- Power consumption is given by,

$$P = VI$$

- In BJT, we have different currents and voltages, to be considered in power calculation. Current I_B and I_C are mainly responsible for the power consumption inside BJT.

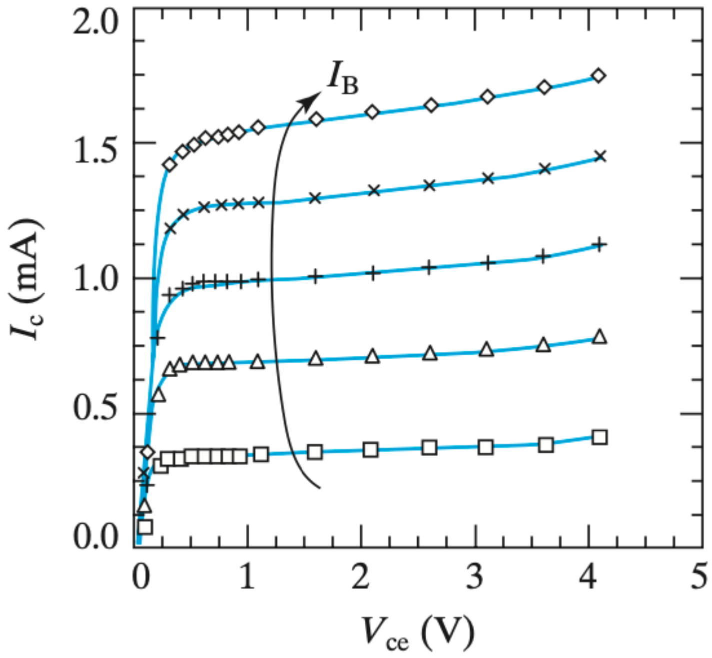
- The total power in the transistor is:

$$P = V_{BE} I_B + V_{CE} I_C$$

- The collector current will be much larger than the base current, and thus the power in the transistor can be simplified to:

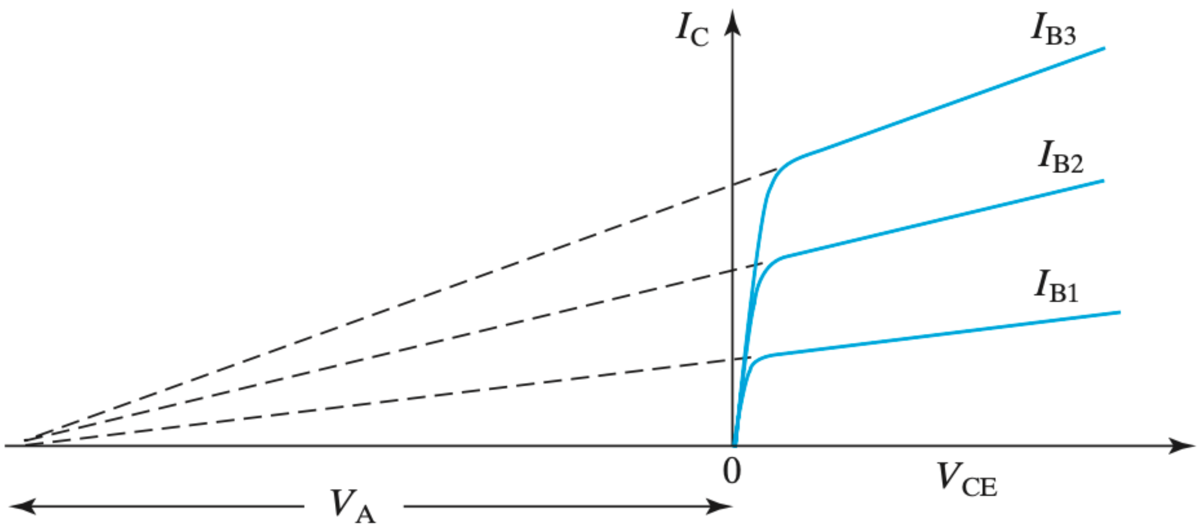
$$P \approx V_{CE} I_C$$

Base-Width Modulation



Output resistance :

$$\boxed{r_0 \equiv \left(\frac{\partial I_C}{\partial V_{CE}}\right)^{-1} = \frac{V_A}{I_C}}$$



Large V_A (large r_o) is desirable for a large voltage gain

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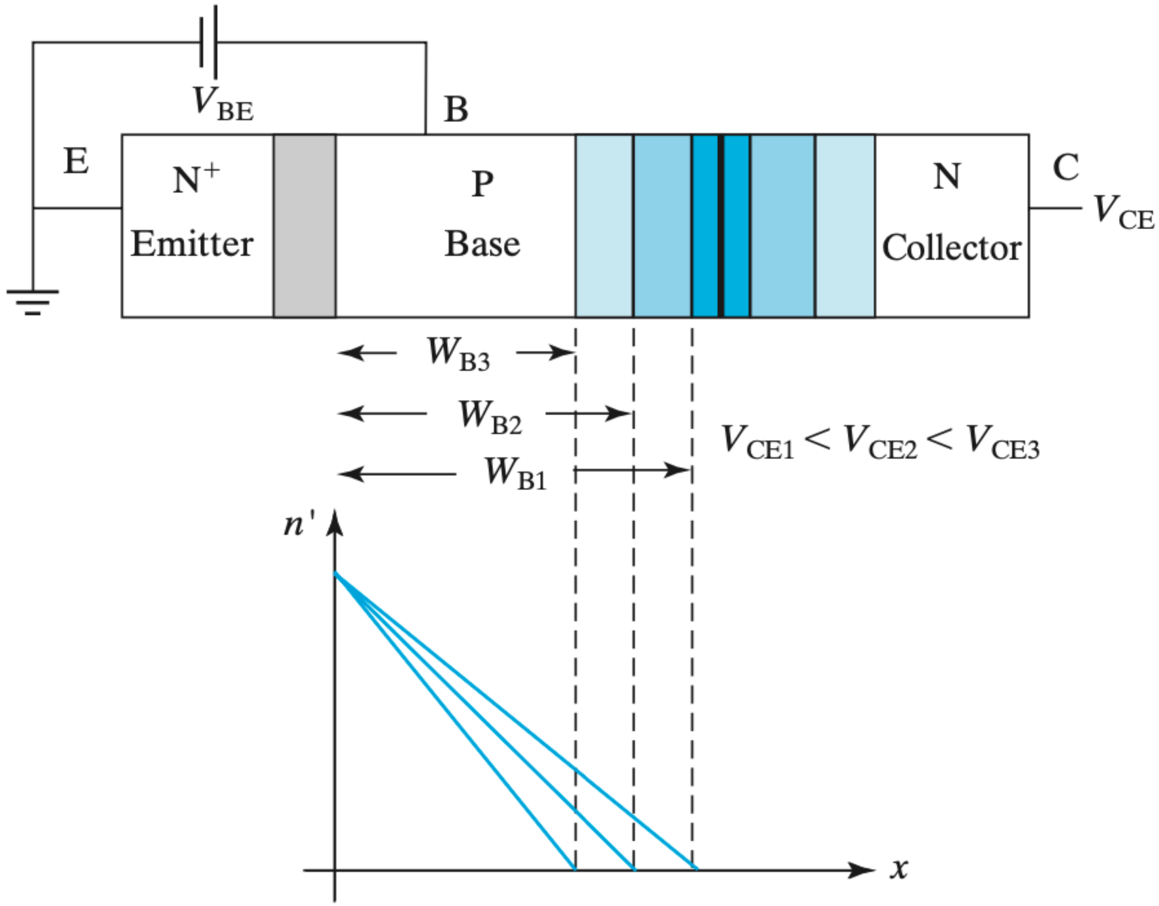
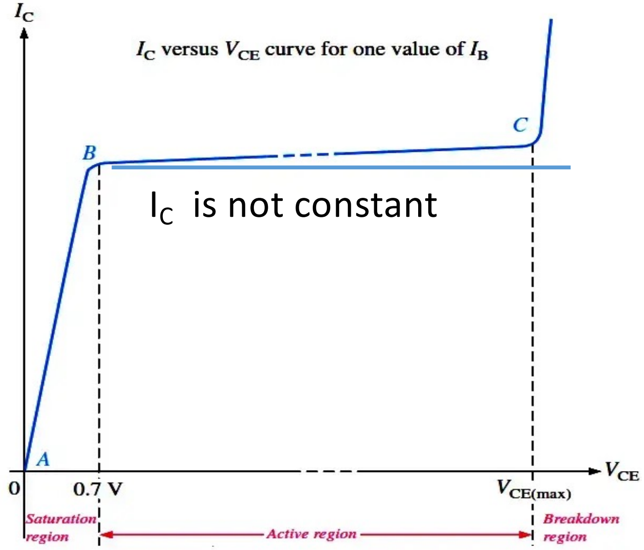
Base-Width Modulation by Collector Voltage





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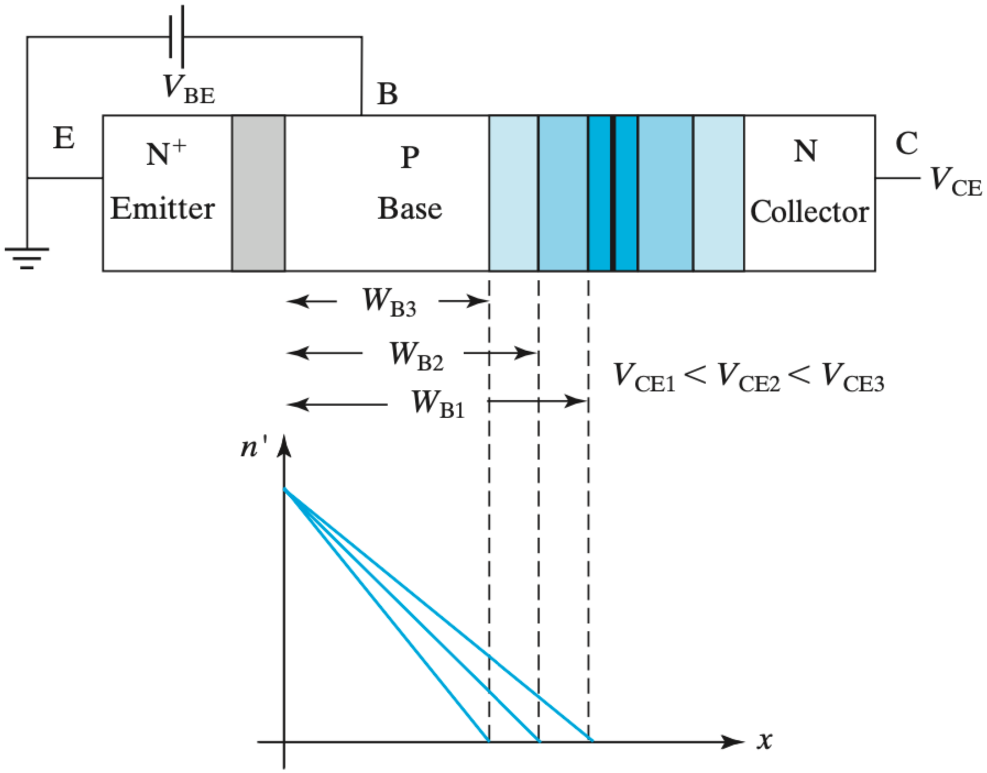
Base-Width Modulation – how can we reduce the impact?

The base-width modulation effect is reduced if we

(A) Increase the base width,
(B) Increase the base doping concentration, N_B, or
(C) Decrease the collector doping concentration, N_C.



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Summary

- The base-emitter junction is usually forward-biased while the base-collector is reverse-biased. V_{BE} determines the collector current, I_C .
- The base (input) current, I_B , is related to I_C by the common-emitter current gain, β_F . This can be related to the common-base current gain, α_F .

$$\alpha_F = \frac{I_C}{I_E} = \frac{\beta_F}{1+\beta_F}$$

- In a npn BJT, an emitter is efficient if the emitter current is mostly the useful electron current injected into the base with little useless hole current (the base current). The emitter efficiency is defined as:

$$\gamma_E = \frac{I_E - I_B}{I_E} = \frac{I_C}{I_C + I_B}$$

- Base-width modulation by V_{CB} results in a significant slope of the I_C vs. V_{CE} curve in the active region (known as the Early effect).

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