Faculty of Engineering

ECE 334: Electronic Circuits

Lecture 2:
BJT Large Signal Model

Agenda

- I & V Notations
- BJT Devices & Symbols
- BJT Large Signal Model

I, V Notations (1)

- It is critical to understand the notation used for voltages and currents in the following discussion of transistor amplifiers.
- This is therefore dealt with explicitly ‘up front’.
- As with dynamic resistance in diodes we will be dealing with a.c. signals superimposed on d.c. bias levels.

I, V Notations (2)

- We will use a capital (upper case) letter for a d.c. quantity (e.g. I, V).
- We will use a lower case letter for a time varying (a.c.) quantity (e.g. i, v)

I, V Notations (3)

- These primary quantities will also need a subscript identifier (e.g. is it the base current or the collector current?).
- For d.c. levels this subscript will be in *upper case*.
- We will use a *lower case subscript* for the a.c. signal bit (e.g. i_b).
- And an *upper case subscript* for the total time varying signal (i.e. the a.c. signal bit plus the d.c. bias) (e.g. i_B).This will be less common.

I, V Notations (4)

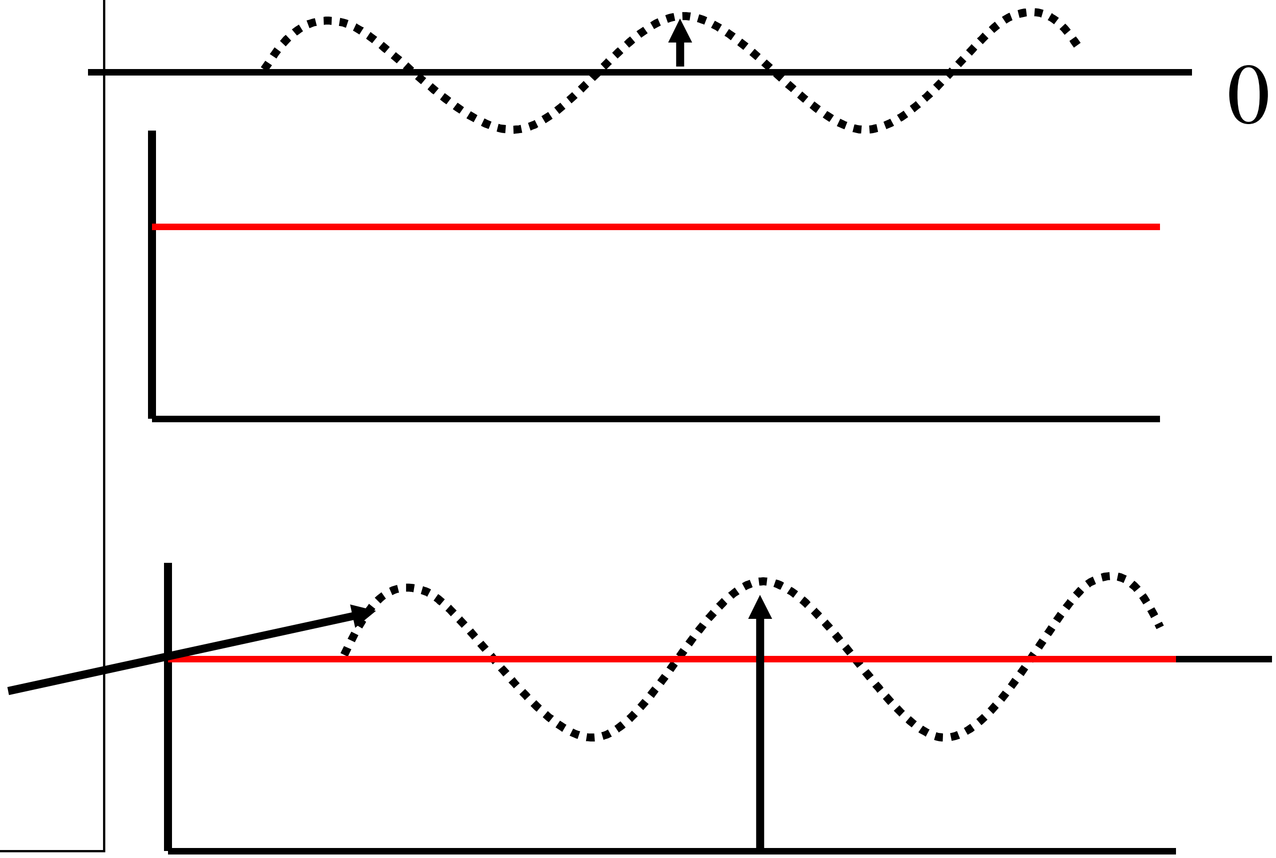
i_b

$+$

I_B

$=$

i_B

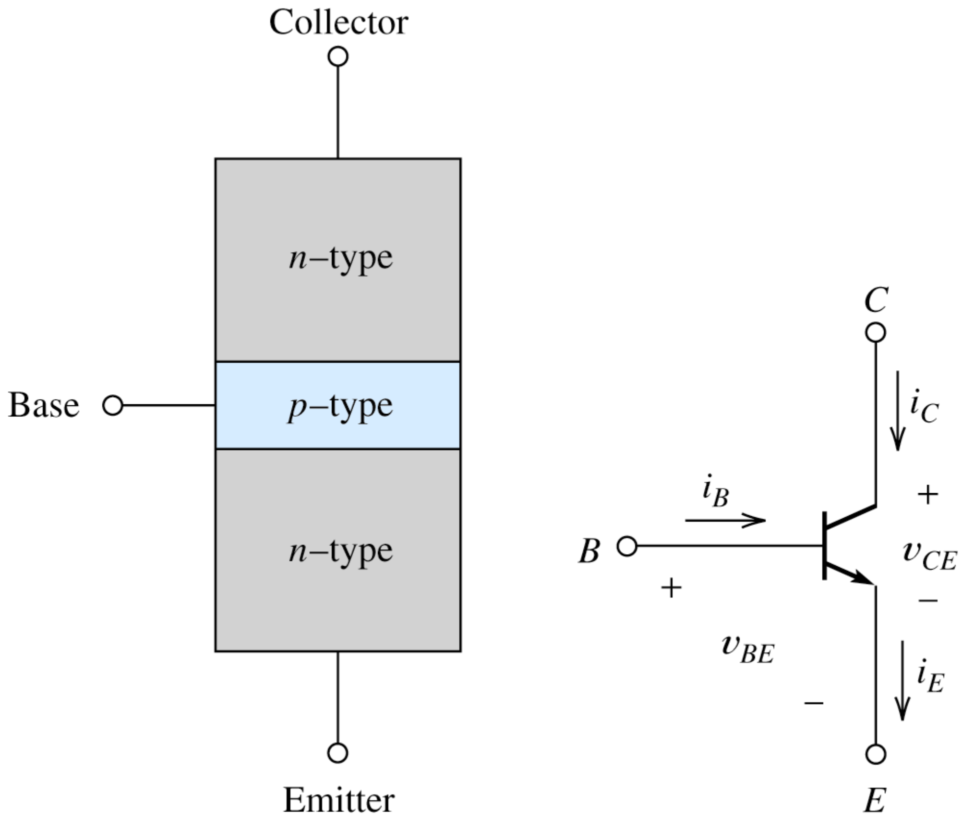


I, V Notations (5)

- It is convention to refer all transistor voltages to the ‘common’ terminal.
- Thus in the CE configuration we would write V_{CE} for a d.c. collector emitter voltage and V_{BE} for a d.c. base emitter voltage.

NPN Bipolar Junction Transistor

- One N-P (Base Collector) diode one P-N (Base Emitter) diode

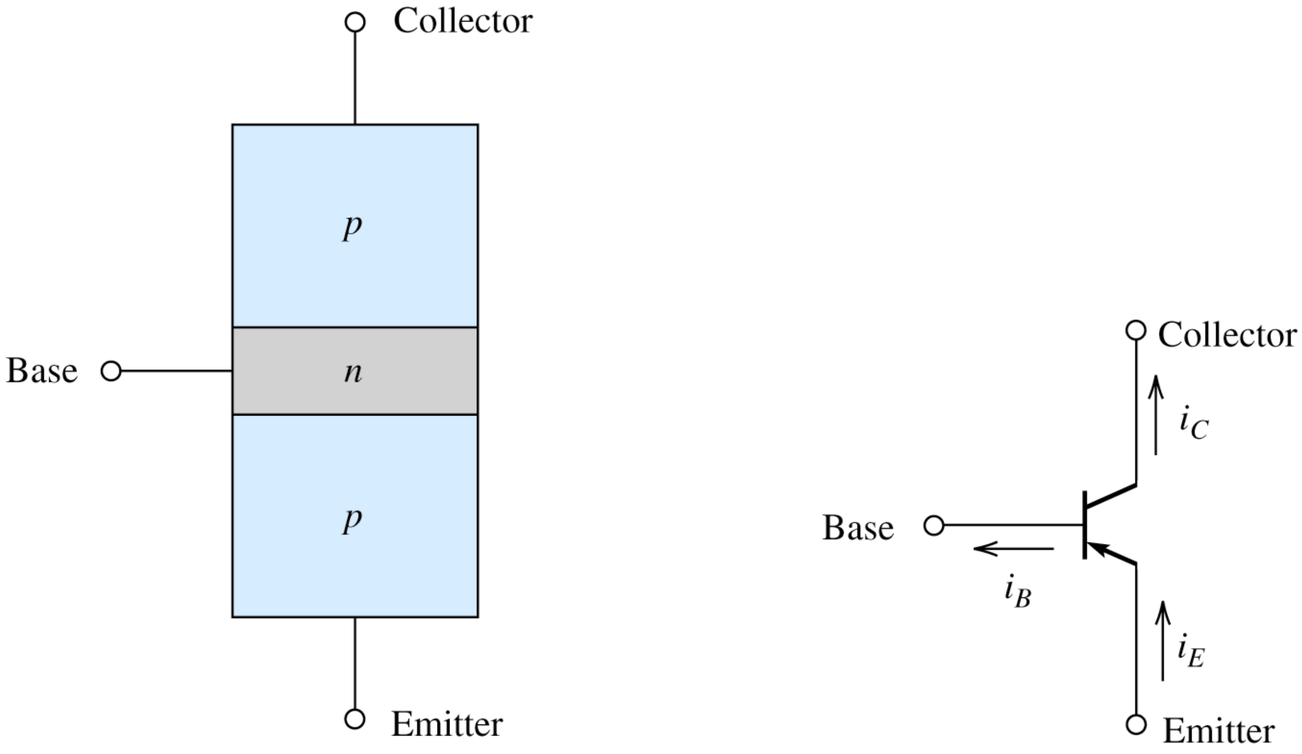


(a) Physical structure (b) Circuit symbol

Figure 13.1 The *npn* BJT.

PNP Bipolar Junction Transistor

- One P-N (Base Collector) diode one N-P (Base Emitter) diode



(a) Physical structure

(b) Circuit symbol with reference directions for currents

Figure 13.13 The *pnp* BJT.

NPN BJT Current flow

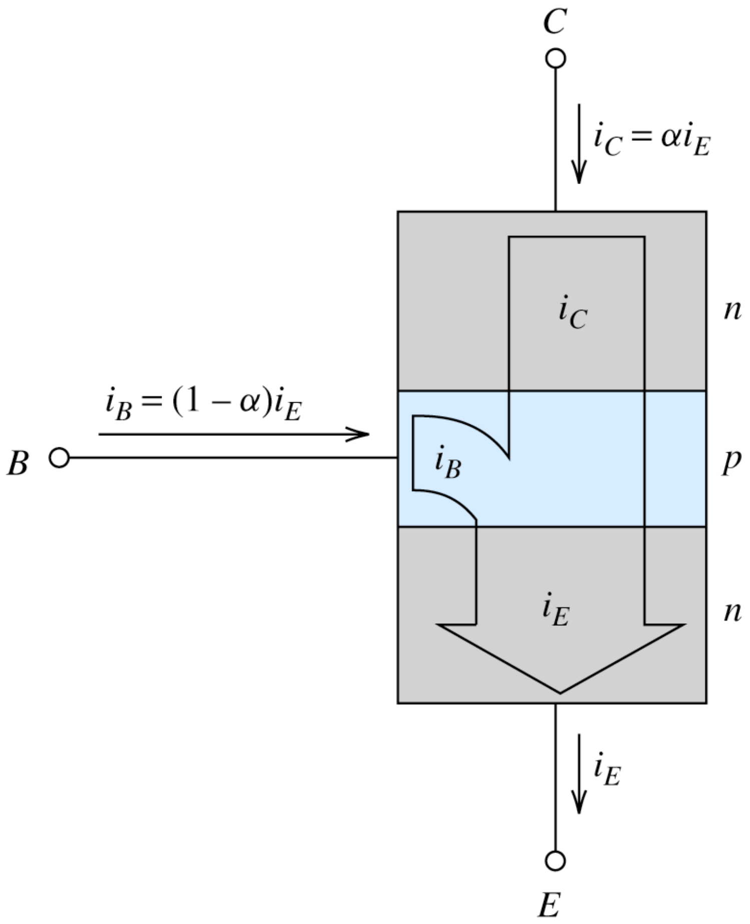
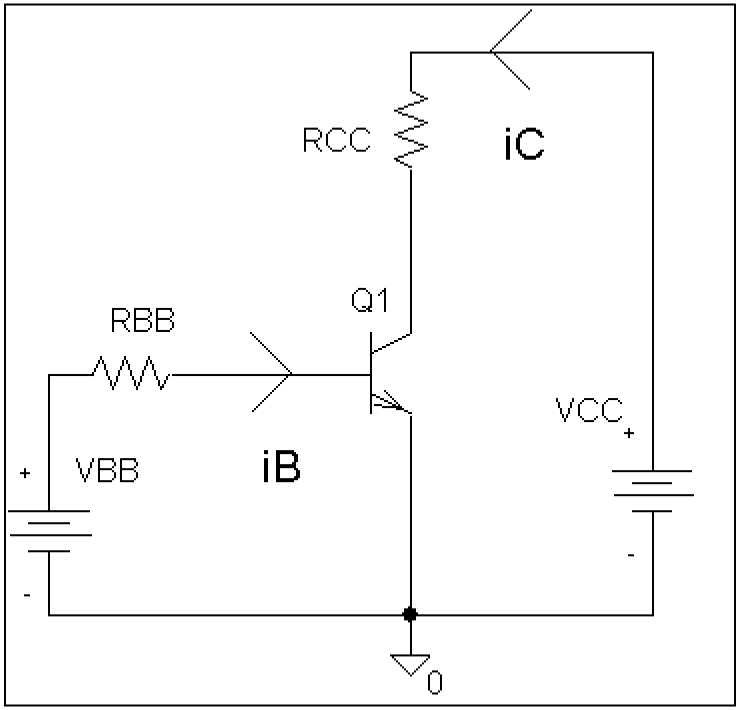


Figure 13.3 Only a small fraction of the emitter current flows into the base (provided that the collector–base junction is reverse biased and the base–emitter junction is forward biased).

BJT α and β

- From the previous figure $i_E = i_B + i_C$
- Define $\alpha = i_C / i_E$
- Define $\beta = i_C / i_B$
- Then $\beta = i_C / (i_E - i_C) = \alpha / (1 - \alpha)$
- Then $i_C = \alpha\, i_E$; $i_B = (1 - \alpha)\, i_E$
- Typically $\beta \approx 100$ for small signal BJTs (BJTs that handle low power) operating in active region (region where BJTs work as amplifiers)

BJT in Active Region



Common Emitter(CE) Connection

- Called CE because emitter is common to both V_{BB} and V_{CC}

BJT in Active Region (2)

- Base Emitter junction is forward biased

- Base Collector junction is reverse biased

- **For a particular i_B, i_C is independent of R_{CC}**
⇒transistor is acting as current controlled current source (i_C is controlled by i_B, and $i_C = \beta\, i_B$)

- Since the base emitter junction is forward biased, from Shockley equation

$$i_C = I_{CS}\left[\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right]$$

BJT in Active Region (3)

- *Normally the above equation is never used to calculate* i_C, i_B *Since for all small signal transistors* $v_{BE} \approx 0.7$. *It is only useful for deriving the small signal characteristics of the BJT.*

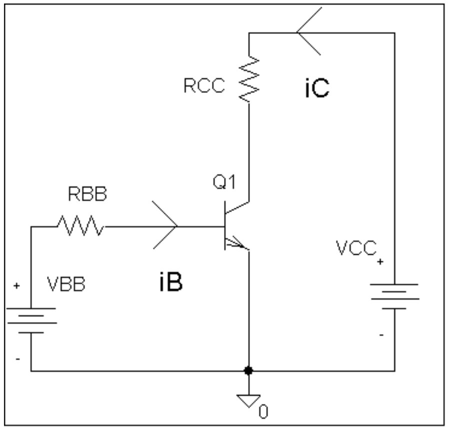
- For example, for the CE connection, i_B can be simply calculated as,

$$i_B = \frac{V_{BB} - V_{BE}}{R_{BB}}$$

or by drawing load line on the base –emitter side

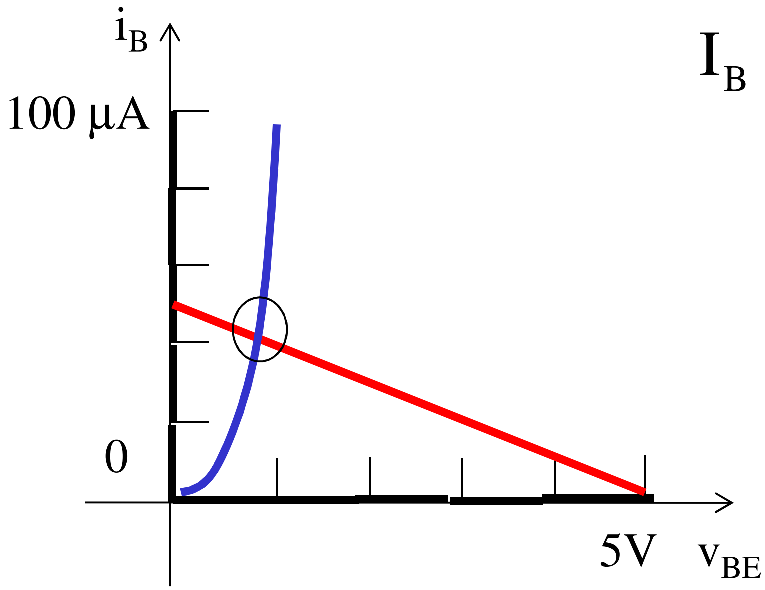
Deriving BJT Operating points in Active Region –An Example

In the CE Transistor circuit shown earlier V_{BB}= 5V, R_{BB}= 107.5 kΩ, R_{CC} = 1 kΩ, V_{CC} = 10V. Find I_B,I_C,V_{CE},β and the transistor power dissipation using the characteristics as shown below



By Applying KVL to the base emitter circuit

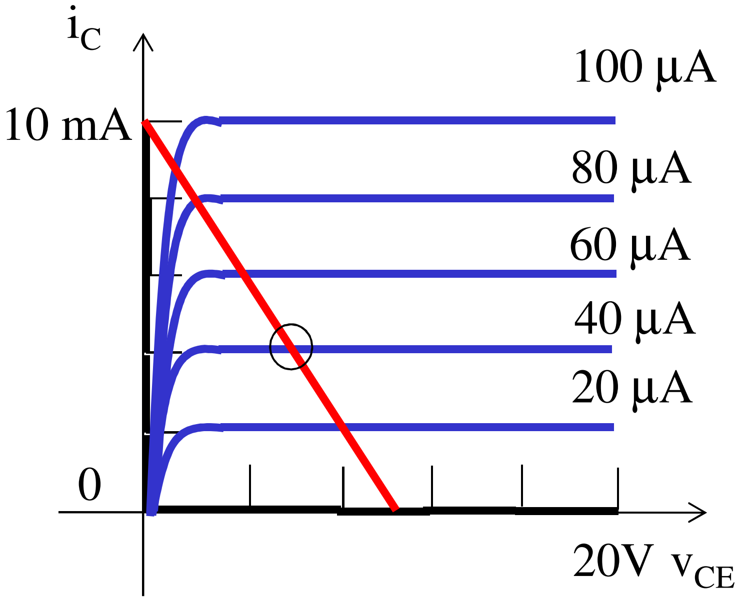
$$I_B = \frac{V_{BB} - V_{BE}}{R_{BB}}$$



By using this equation along with the i_B / v_{BE} characteristics of the base emitter junction, I_B = 40 µA

Deriving BJT Operating points in Active Region –An Example (2)

By Applying KVL to the collector emitter circuit



$$I_C = \frac{V_{CC} - V_{CE}}{R_{CC}}$$

By using this equation along with the i_C / v_{CE} characteristics of the base collector junction, $i_C = 4$ mA, $V_{CE} = 6$V

$$\beta = \frac{I_C}{I_B} = \frac{4mA}{40\mu A} = 100$$

Transistor power dissipation = $V_{CE}I_C$ = 24 mW

We can also solve the problem without using the characteristics if β and V_{BE} values are known

BJT in Cutoff Region

- Under this condition $i_B = 0$

- As a result i_C becomes negligibly small

- Both base-emitter as well base-collector junctions may be reverse biased

- Under this condition the BJT can be treated as an off switch

BJT in Saturation Region

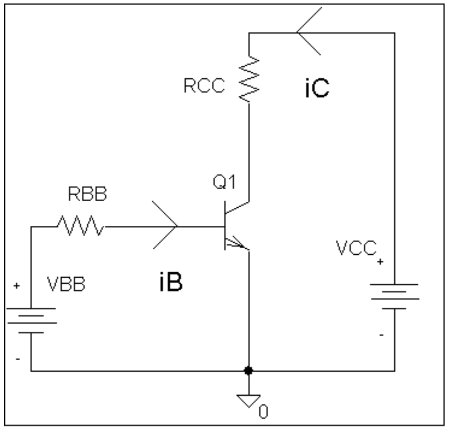
- Under this condition $i_C / i_B < \beta$ in active region

- Both base emitter as well as base collector junctions are forward biased

- $V_{CE} \approx 0.2$ V

- Under this condition the BJT can be treated as an on switch

BJT in Saturation Region (2)

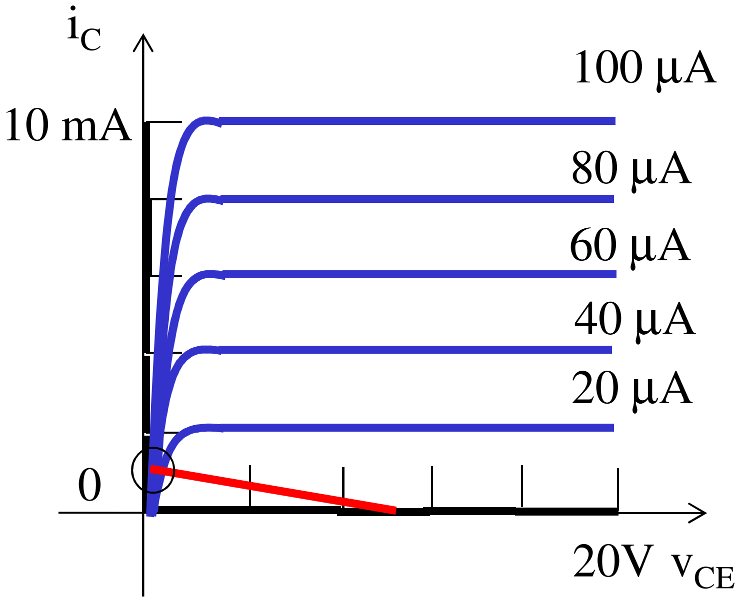


- A BJT can enter saturation in the following ways (refer to the CE circuit)
- For a particular value of i_B, if we keep on increasing R_{CC}
- For a particular value of R_{CC}, if we keep on increasing i_B
- For a particular value of i_B, if we replace the transistor with one with higher β

BJT in Saturation Region – Example 1

In the CE Transistor circuit shown earlier $V_{BB}= 5V$, $R_{BB}= 107.5\ k\Omega$, $R_{CC} = 10\ k\Omega$, $V_{CC} = 10V$. Find I_B,I_C,V_{CE},β and the transistor power dissipation using the characteristics as shown below

Here even though I_B is still 40 μA; from the output characteristics, I_C can be found to be only about 1mA and $V_{CE} \approx 0.2V (\Rightarrow V_{BC} \approx 0.5V$ or base collector junction is forward biased (how?))



$$\beta = I_C / I_B = 1mA/40\ \mu A = 25 < 100$$

BJT in Saturation Region – Example 2

In the CE Transistor circuit shown earlier V_{BB}= 5V, R_{BB}= 43 kΩ, R_{CC} = 1 kΩ, V_{CC} = 10V. Find I_B,I_C,V_{CE},β and the transistor power dissipation using the characteristics as shown below

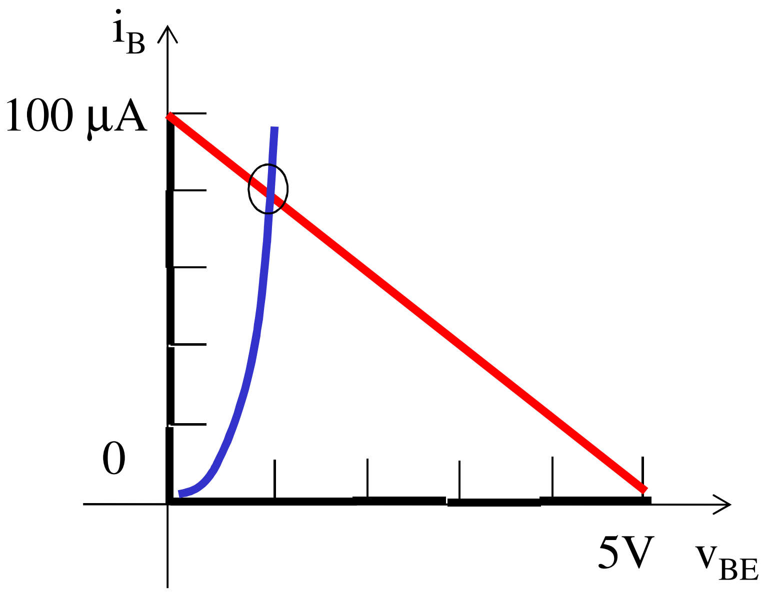
Here I_B is 100 μA from the input characteristics; I_C can be found to be only about 9.5 mA from the output characteristics and $V_{CE} \approx 0.5V (\Rightarrow V_{BC} \approx 0.2V$ or base collector junction is forward biased (how?))

$$\beta = I_C / I_B = 9.5 \text{ mA}/100\ \mu\text{A} = 95 < 100$$

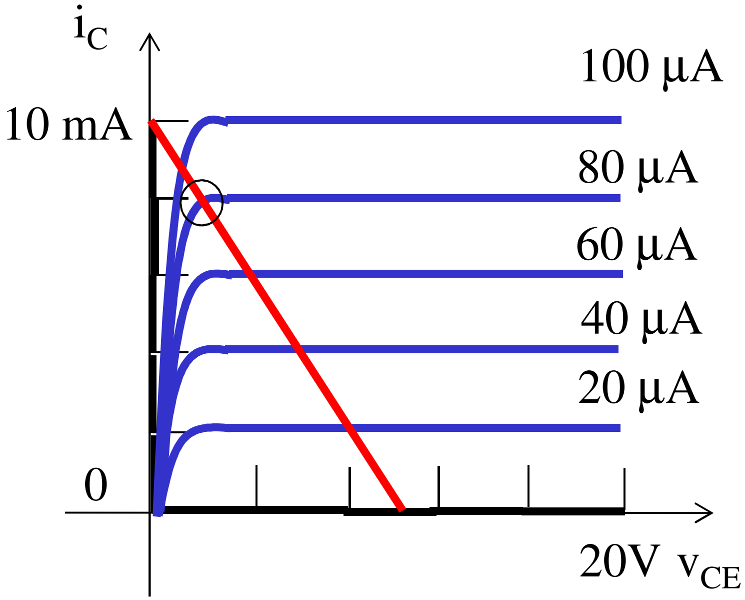
Transistor power dissipation = $V_{CE}I_C \approx 4.7$ mW

Note: In this case the BJT is not in very hard saturation

BJT in Saturation Region – Example 2 (2)



Input Characteristics



Output Characteristics

BJT in Saturation Region – Example 3

In the CE Transistor circuit shown earlier V_{BB}= 5V, V_{BE} = 0.7V R_{BB}= 107.5 kΩ, R_{CC} = 1 kΩ, V_{CC} = 10V, β = 400. Find I_B,I_C,V_{CE}, and the transistor power dissipation using the characteristics as shown below

By Applying KVL to the base emitter circuit

$$I_B = \frac{V_{BB} - V_{BE}}{R_{BB}} = 40\mu A$$

Then $I_C = \beta I_B$= 400*40 μA = 16000 μA

and $V_{CE} = V_{CC}$-R_{CC*} I_C =10- 0.016*1000 = -6V(?)

But V_{CE} cannot become negative (since current can flow only from collector to emitter).

Hence the transistor is in saturation

BJT in Saturation Region – Example 3(2)

Hence $V_{CE} \approx 0.2V$

$\therefore I_C = (10 - 0.2) / 1 = 9.8$ mA

Hence the operating $\beta = 9.8$ mA / 40 μA = 245

BJT Operating Regions at a Glance (1)

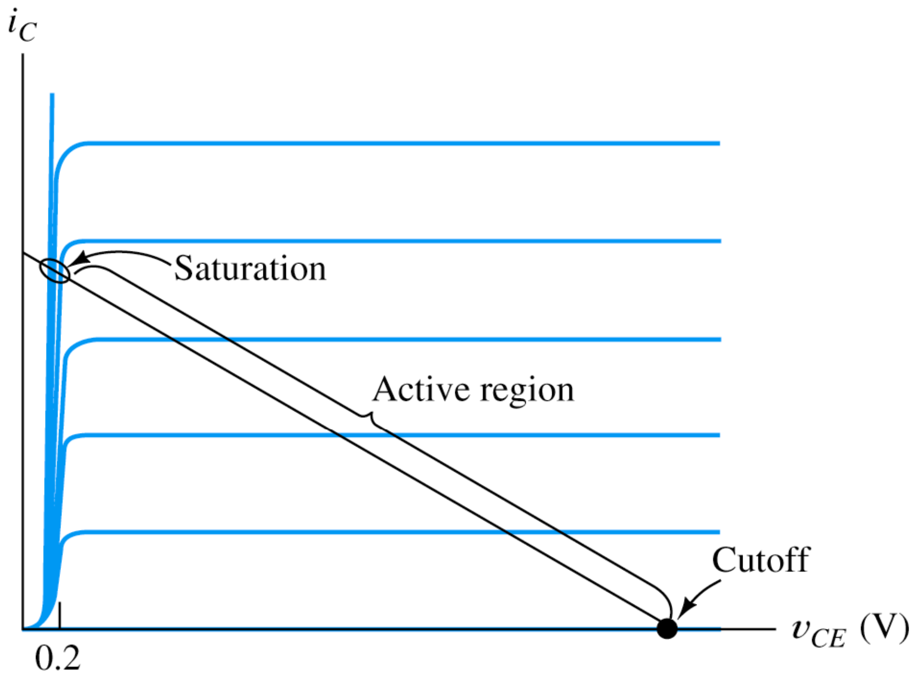
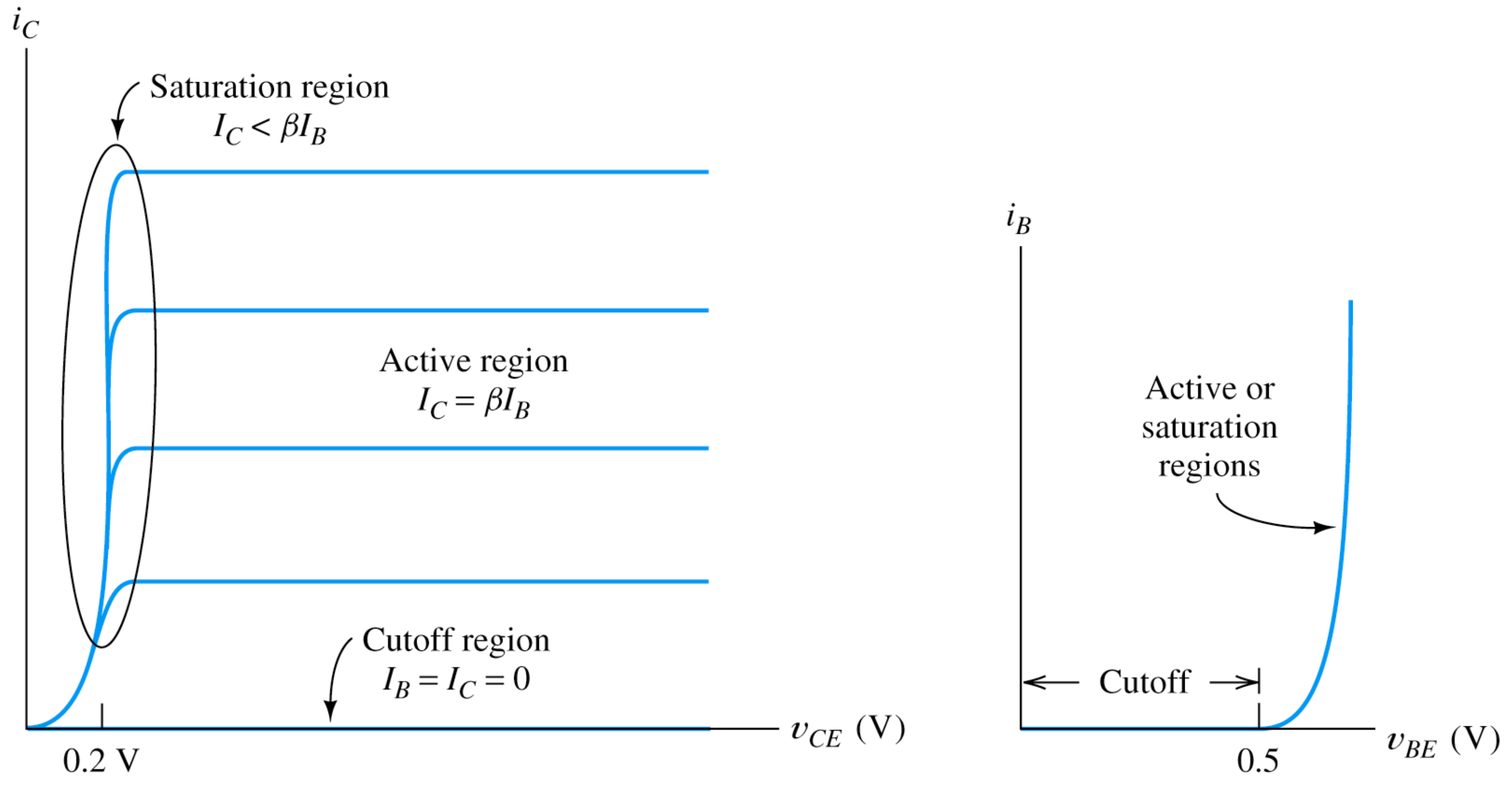


Figure 13.12 Amplification occurs in the active region. Clipping occurs when the instantaneous operating point enters saturation or cutoff.
In saturation, $v_{CE} \cong 0.2$ V.

BJT Operating Regions at a Glance (2)



(a) Output characteristic

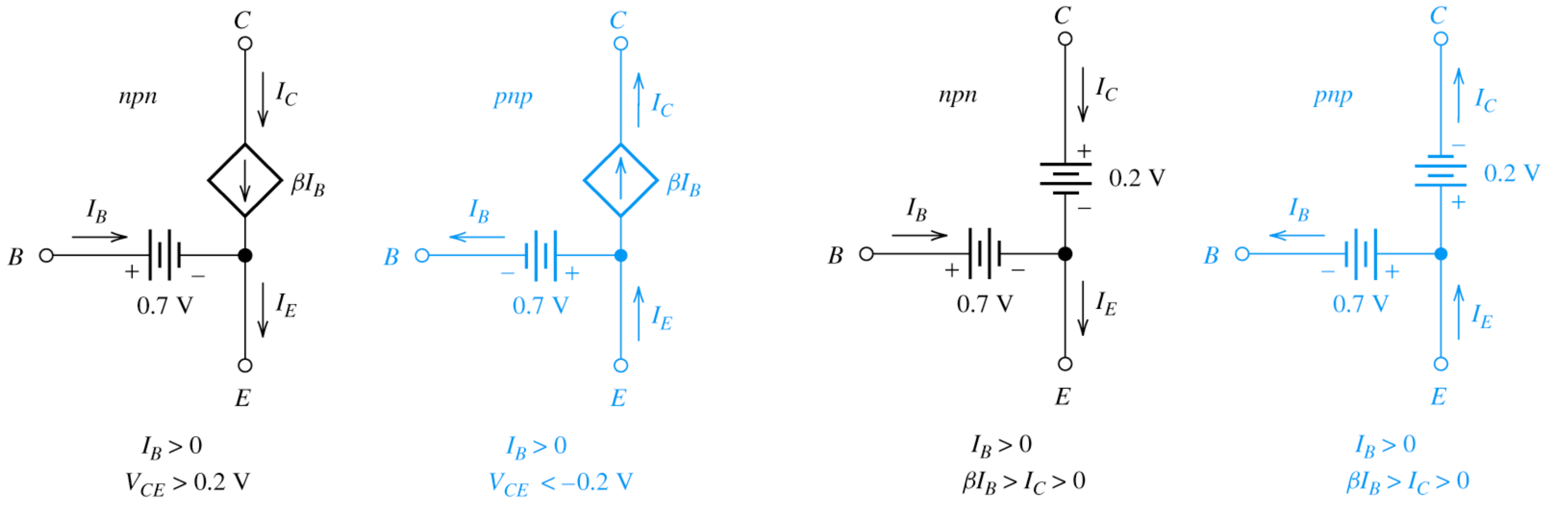
(b) Input characteristic

Figure 13.17 Regions of operation on the characteristics of an *npn* BJT.

BJT Large-signal (DC) Model (1)

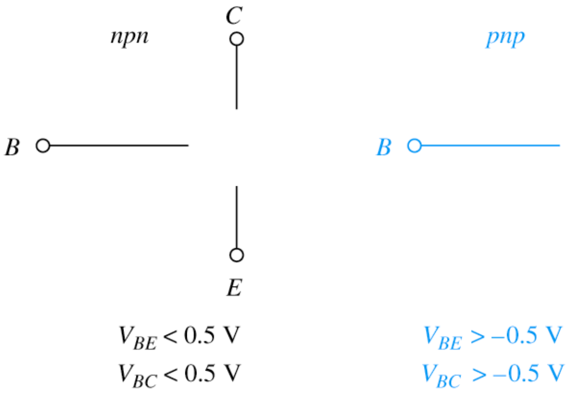
- $i_E = i_B + i_C$
- $\alpha = i_C / i_E$
- $\beta = i_C / i_{B\,=} = \alpha /(1- \alpha)$
- $i_C = \alpha\, i_E\, ;\, i_B = (1-\alpha)\, i_E$

BJT Large-signal (DC) Model (2)



(a) Active region

(b) Saturation region



(c) Cutoff region

Figure 13.16 BJT large-signal models. (*Note:* Values shown are appropriate for typical small-signal silicon devices at a temperature of 300 K.)