Lecture Notes
for
Semiconductor Devices and Circuits : BJT

(Electronics : PHYS4008)

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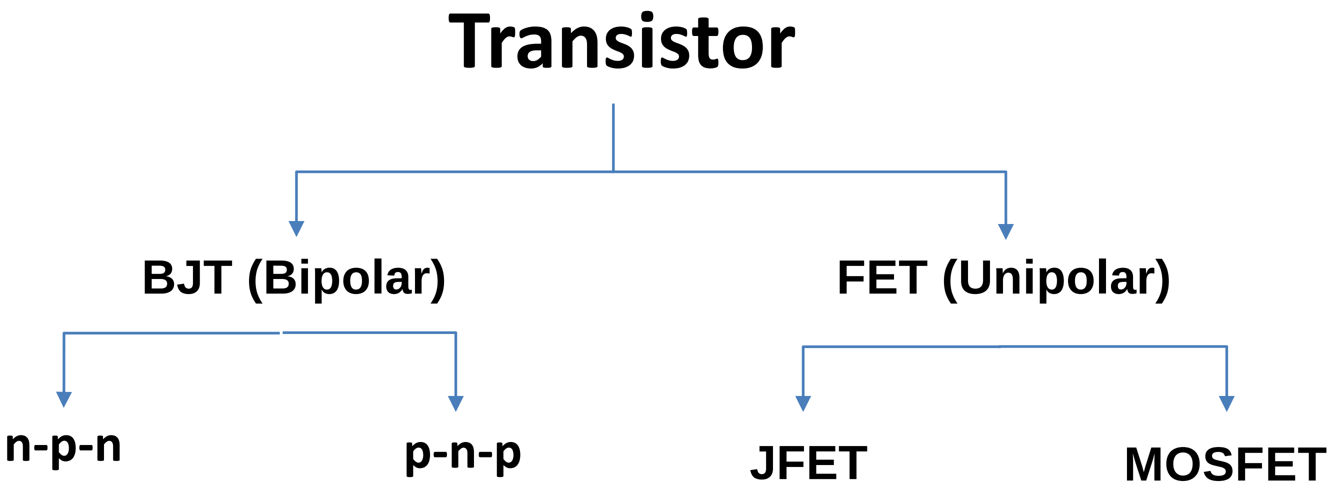
Contents

1. Transistor & Type

- A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power.
- It is composed of semiconductor material with at least three terminals for connection to an external circuit.

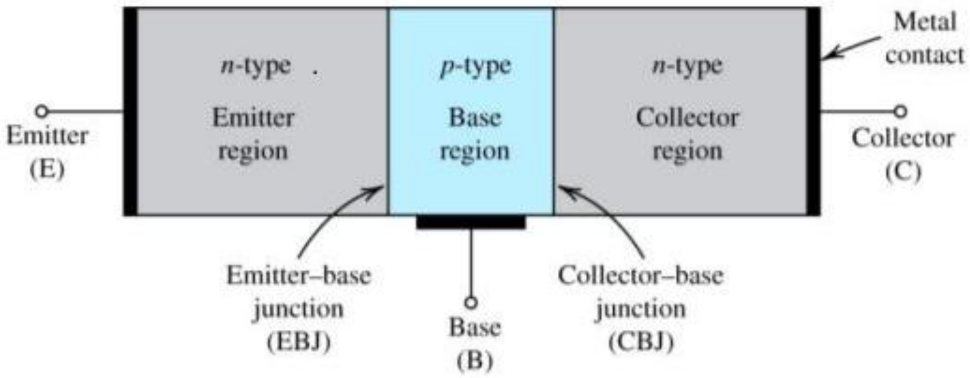


2. Bipolar Junction transistor (BJT)

- It is a three terminals current controlled active device. It is called Bipolar as it lies on the two types of charge carriers

- BJT consist of a Si (or Ge) crystal in which a layer of n type Si (or Ge) is sandwiched between two layer of p type Si (or Ge) called p-n-p Transistor . Alternatively, a Transistor may also consist of a layer of p type Si (or Ge) sandwiched between two layer of n type Si(or Ge) called n-p-n Transistor.

Simplified physical structure



- Device is constructed such that BJT does NOT act as two diodes back to back (when voltages are applied to all three terminals).

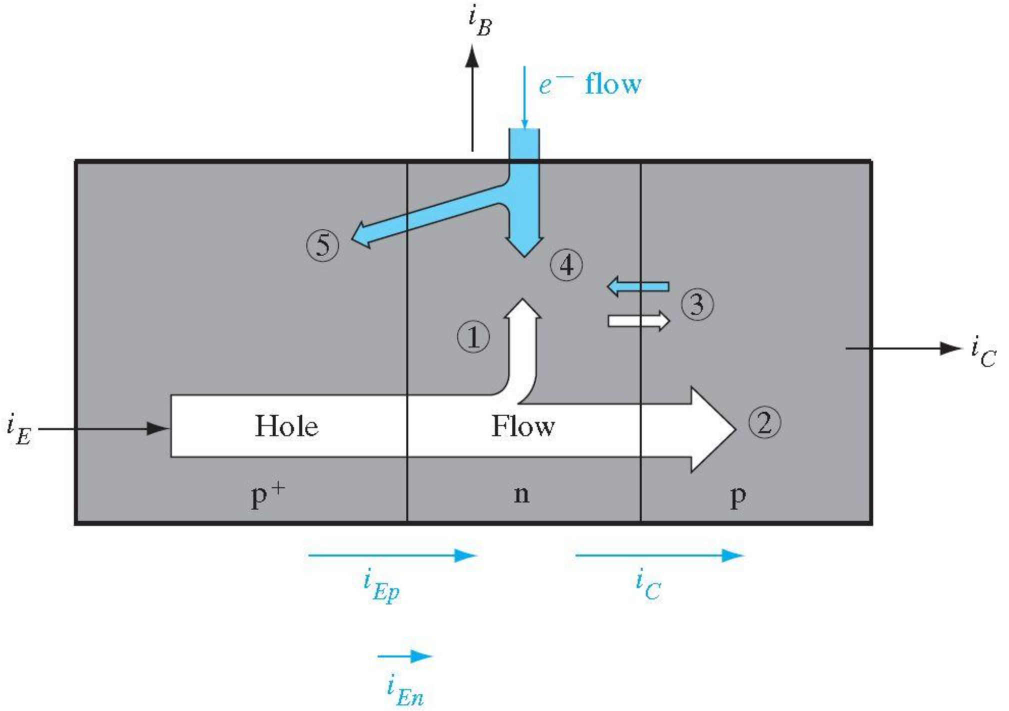
2.1 Mechanism of Transistor

- The forward-biased junction that injects holes into the center N- region is called the emitter junction.

- The reverse-biased junction that collects the injected holes is called the collector junction.

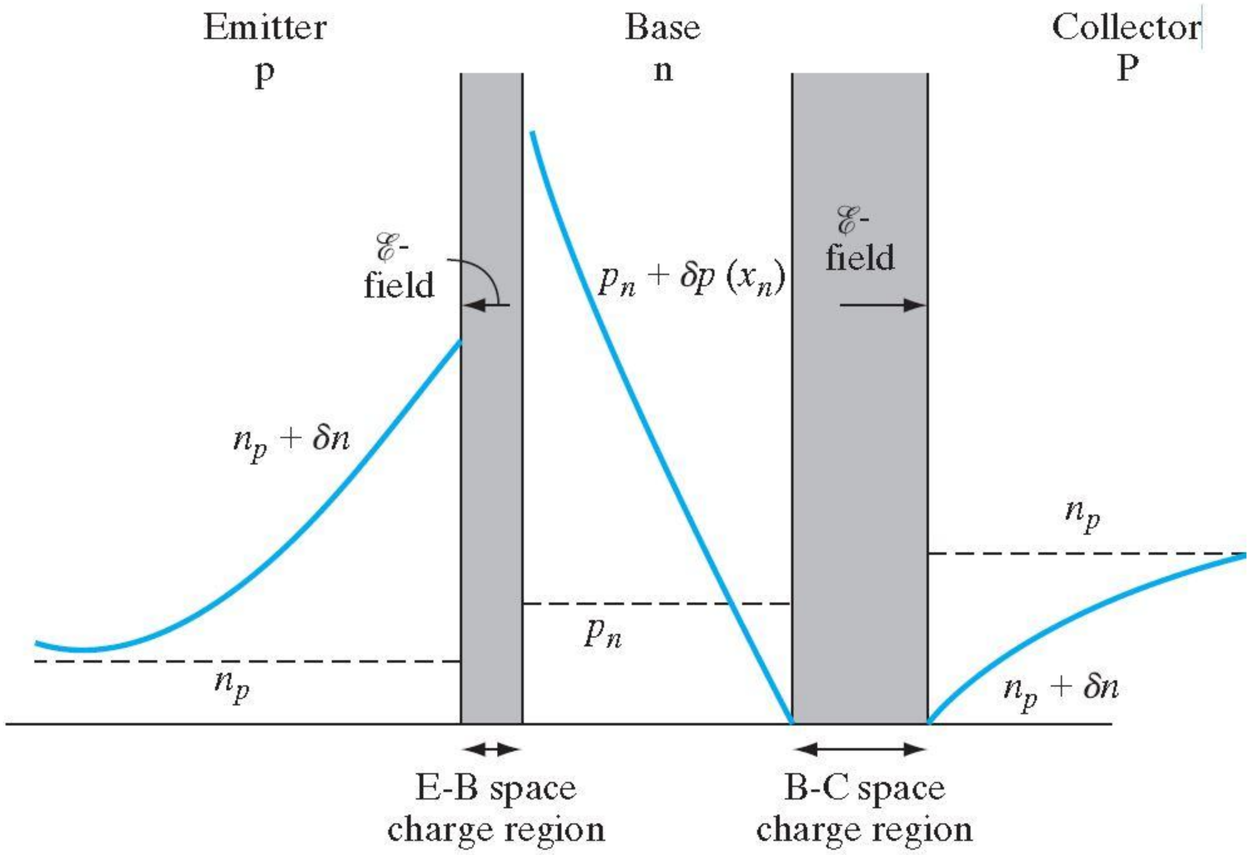
- The p+ region, which serves as the source of injected holes, is called the emitter.

- the p-region into which the holes are swept by the reverse-biased junction is called the collector. The center n-region is called the base.



2.2 Minority carrier concentration in a transistor

- As the Potential barrier at the emitter base junction is lowered due to forward biasing the Minority carrier concentration across it increases.
- As the doping of emitter is much higher the minority carrier injected into the base is much higher and P_n is much higher than n_p.
- As the collector base junction is reverse bias the minority concentration across this junction is lowered



(a) Electron distributions in the emitter and collector

2.3 Region of BJT Operation

ii) **Cut-off region**: Both emitter junction and collector junction are in reversed bias i.e. The transistor is off. There is no conduction between the collector and the emitter. ($I_B = 0$ therefore $I_C = 0$)

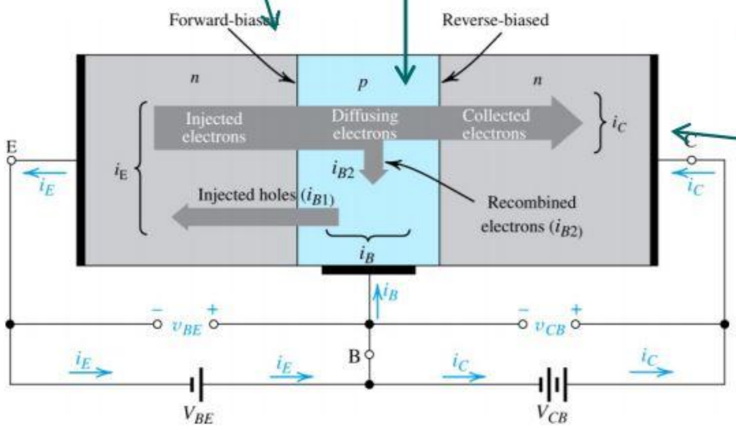
ii) Active region:

The transistor is on. The collector current is proportional to and controlled by the base current ($I_C = \beta I_B$) and relatively insensitive to V_{CE}. In this region the transistor can be an amplifier.

BE junction is forward biased ($v_{BE} = V_{D0}$)

As Emitter is heavily doped, a large number of electrons diffuse into the base (only a small fraction combine with holes)

The number of these electrons scales as e^{v_{BE}/V_T}



- If the base is "thin" these electrons get near the depletion region of BC junction and are swept into the collector if $v_{CB} \geq 0$ ($v_{BC} \leq 0$: **BC junction is reverse biased**!)

$$i_C = I_S e^{v_{BE}/V_T}$$

- In this picture, i_c is independent of v_{BC} (and v_{CE}) as long as

$$v_{BC} = v_{BE} - v_{CE} = V_{D0} - v_{CE} \leq 0$$
$$v_{CE} \geq V_{D0}$$

Active mode:

$$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$
$$i_C = I_S e^{v_{BE}/V_T}$$
$$v_{CE} \geq V_{D0}$$

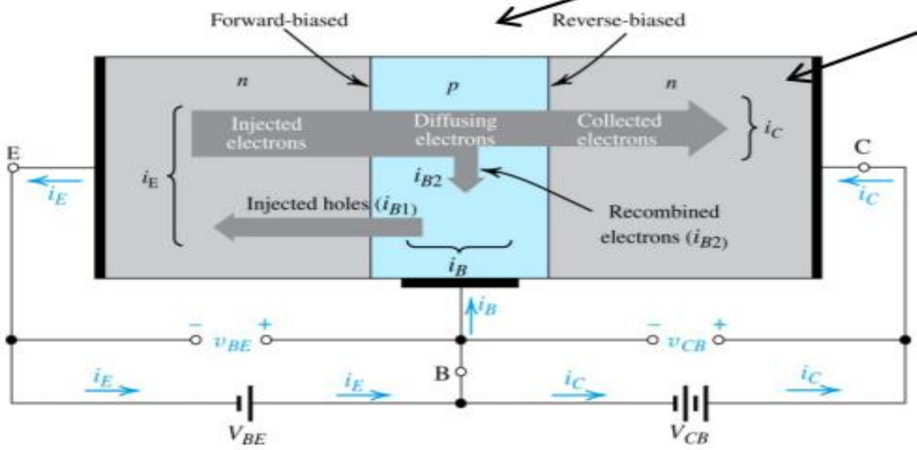
- Base current is also proportional to e^{v_{BE}/V_T} and therefore, $i_C : i_B = i_C/\beta$

F. Najmabadi, ECE65, Winter 2012

iii) Saturation region: The transistor is on. The collector current varies very little with a change in the base current in the saturation region. The V_{CE} is small, a few tenths of a volt. The collector current is strongly dependent on V_{CE} unlike in the active region. It is desirable to operate transistor switches in or near the saturation region when in their on state.

- **BE junction is forward biased** ($v_{BE} = V_{D0}$)

Similar to the active mode, a large number of electrons diffuse into the base.



➢ For $v_{BC} \geq 0$ **BC junction is forward biased** and a diffusion current will set up, reducing i_C .

1. Soft saturation: $v_{CE} \geq 0.3$ V (Si)*
   $v_{BC} \leq 0.4$ V (Si), diffusion current is small and i_C is very close to its active-mode level.
2. Deep saturation region: $0.1 < v_{CE} < 0.3$ V (Si) or $v_{CE} \approx 0.2$ V $= V_{sat}$ (Si), i_C is smaller than its active-mode level ($i_C < \beta\, i_B$).
   - Called saturation as i_C is set by outside circuit & does not respond to changes in i_B.
3. Near cut-off: $v_{CE} \leq 0.1$ V (Si)
   Both i_C & i_B are close to zero.

"Deep" Saturation mode:

$$i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

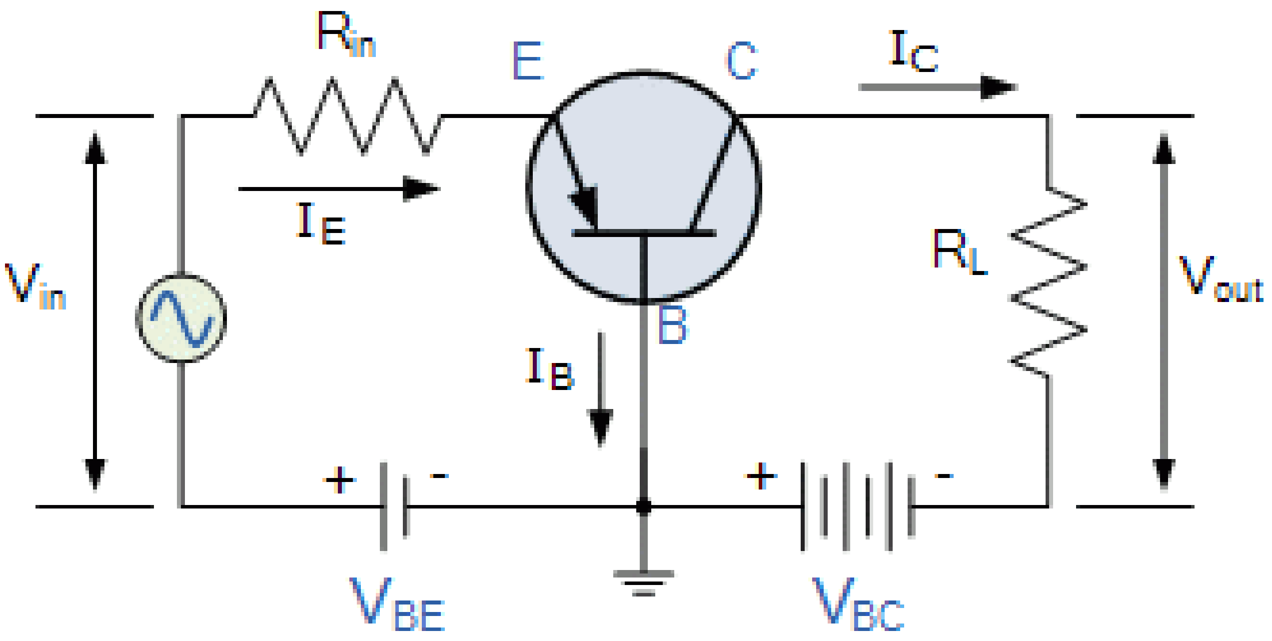
$$i_C < \beta\, i_B$$

$$v_{CE} \approx V_{sat}$$

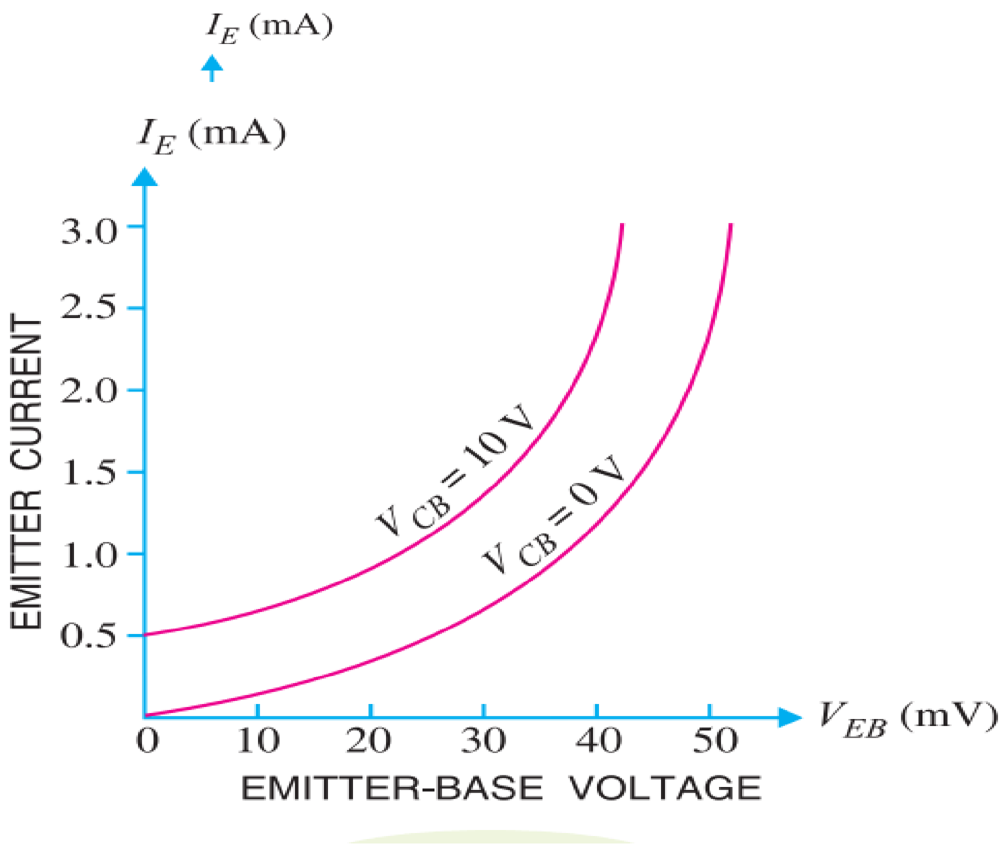
* Sedra & Smith includes this in the active region, i.e., BJT is in active mode as long as $v_{CE} > 0.3$ V.

2.4 Transistor connection

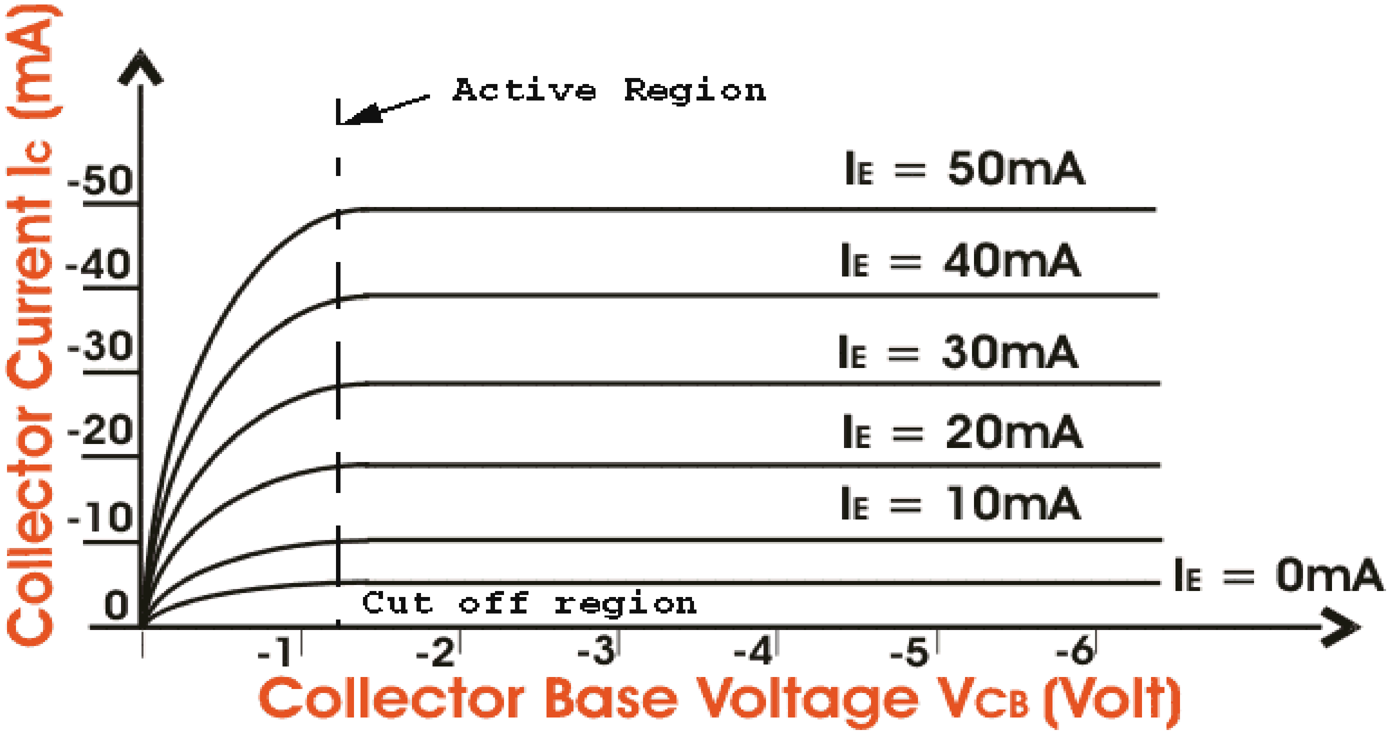
i) Common Base Connection



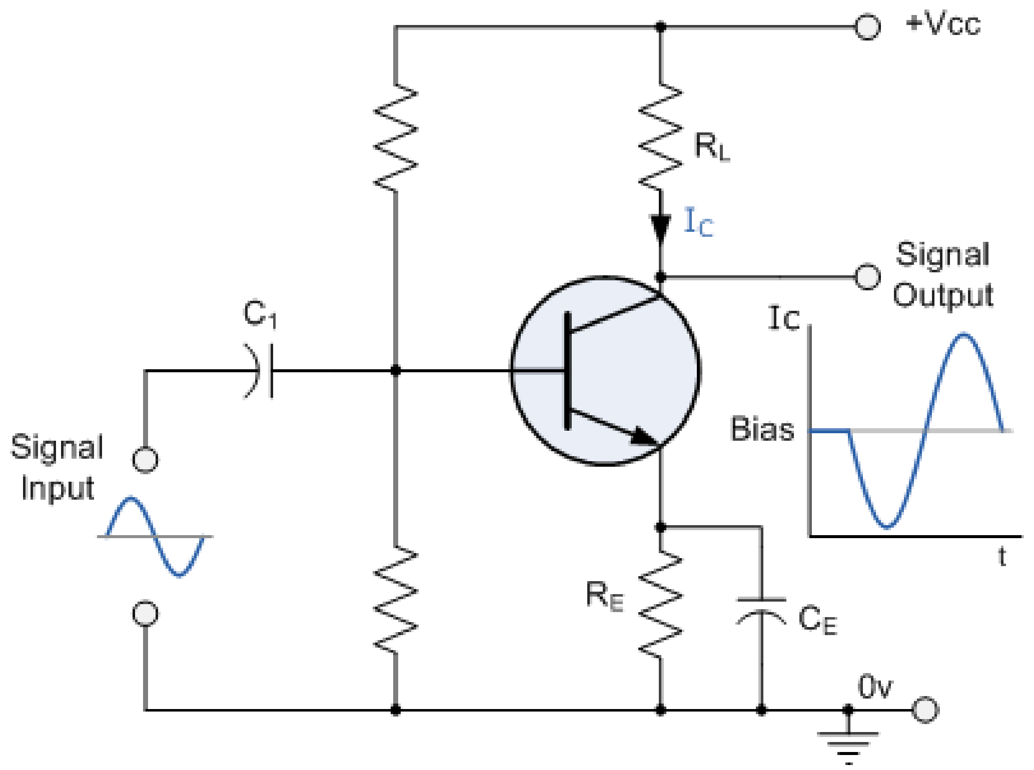
Input characteristics



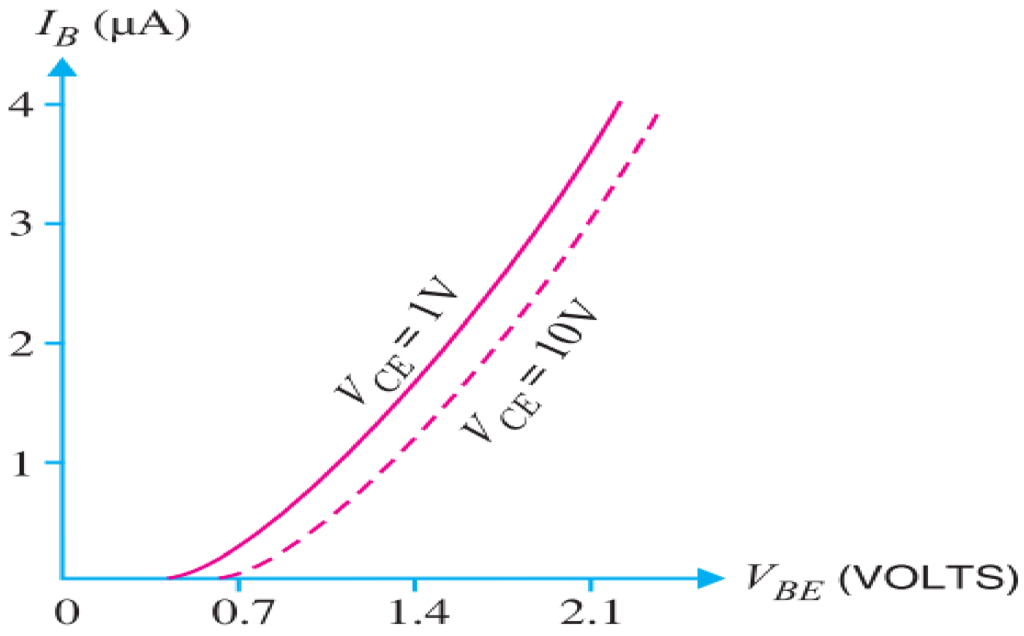
Output characteristics



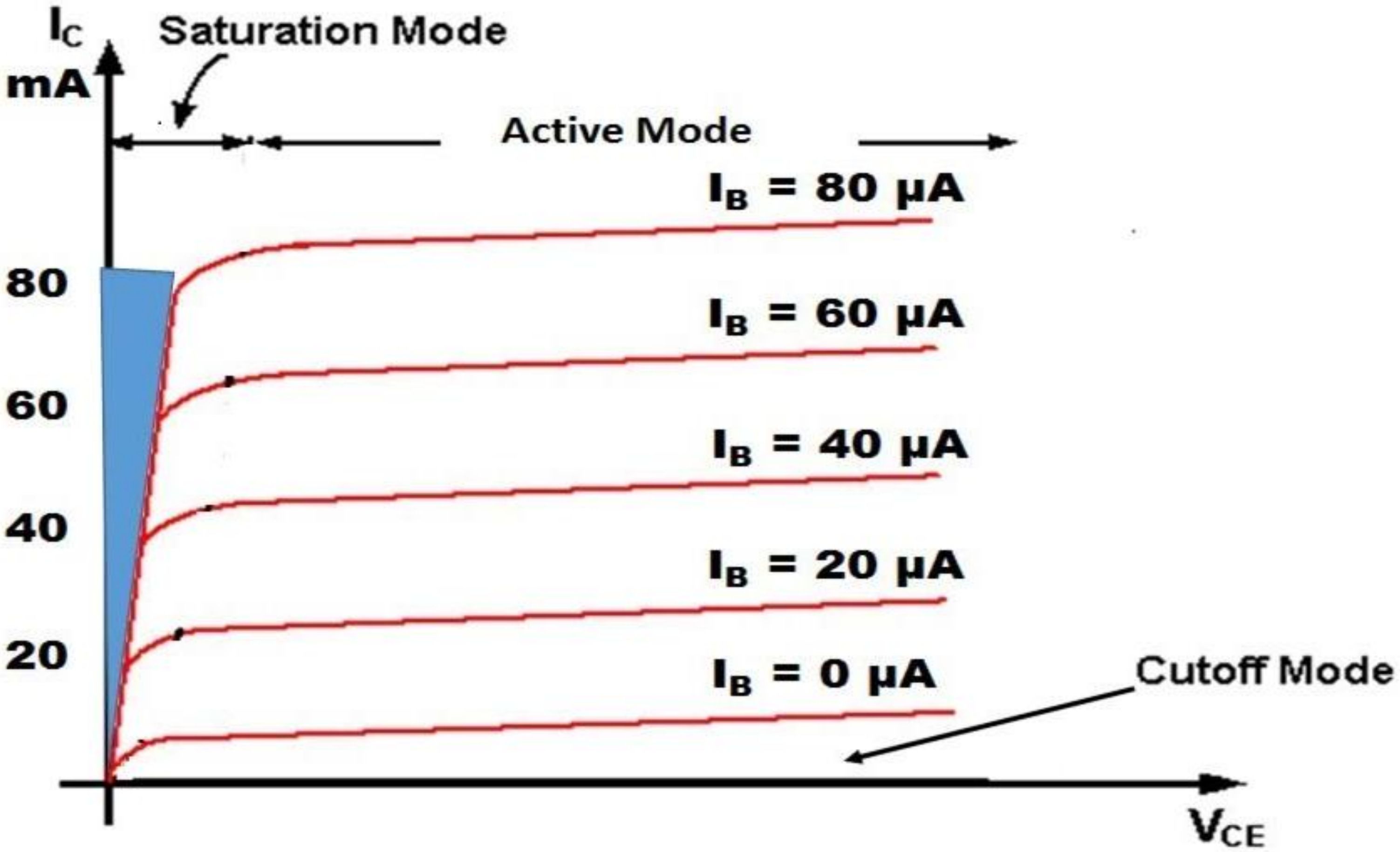
ii) Common Emitter Connection



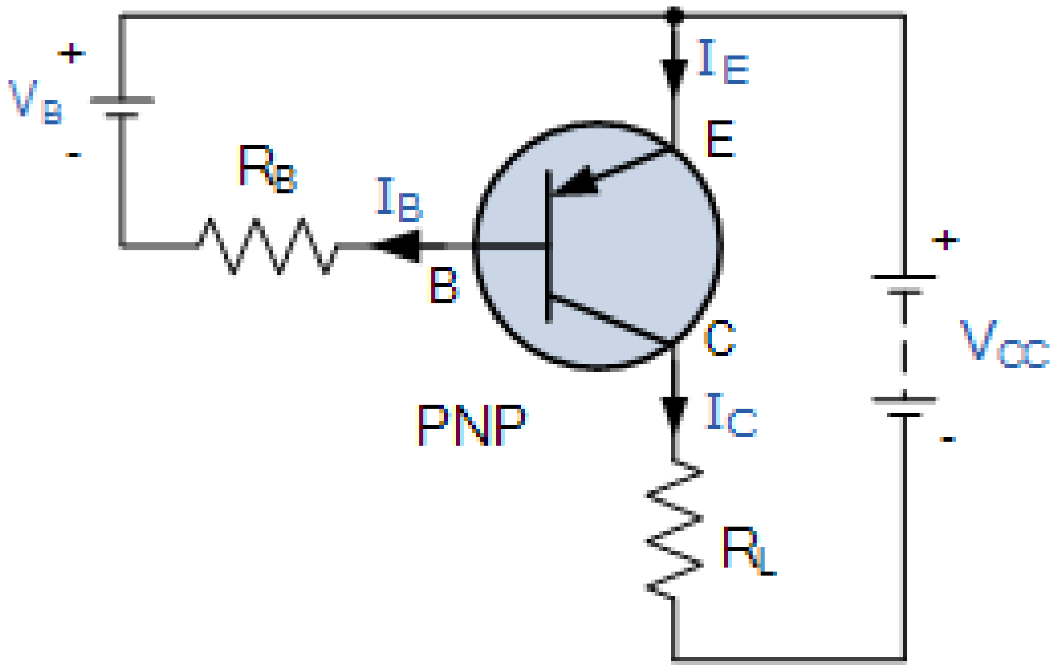
Input characteristics

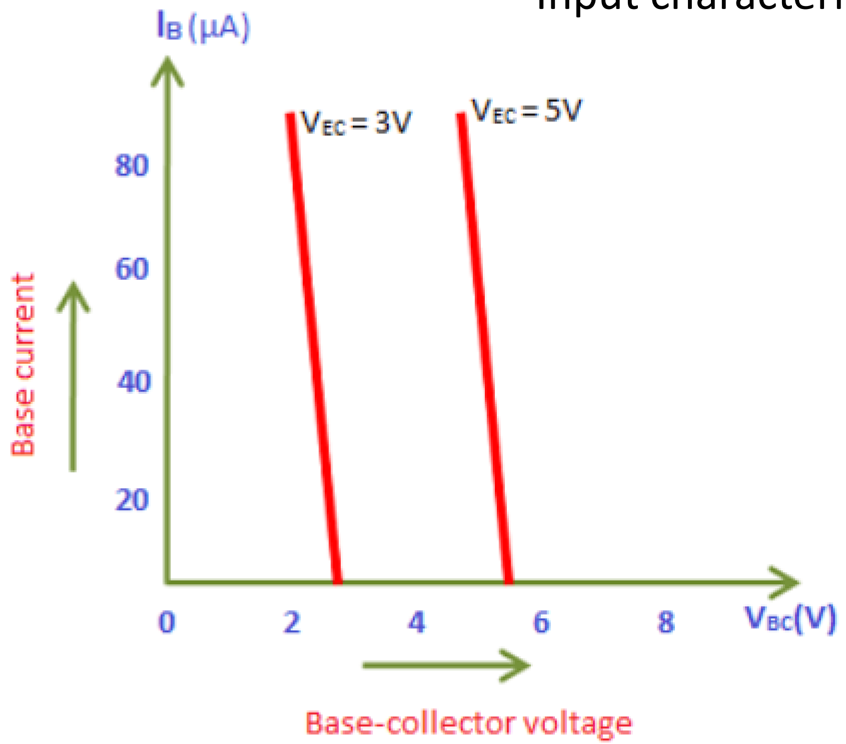


Output characteristics



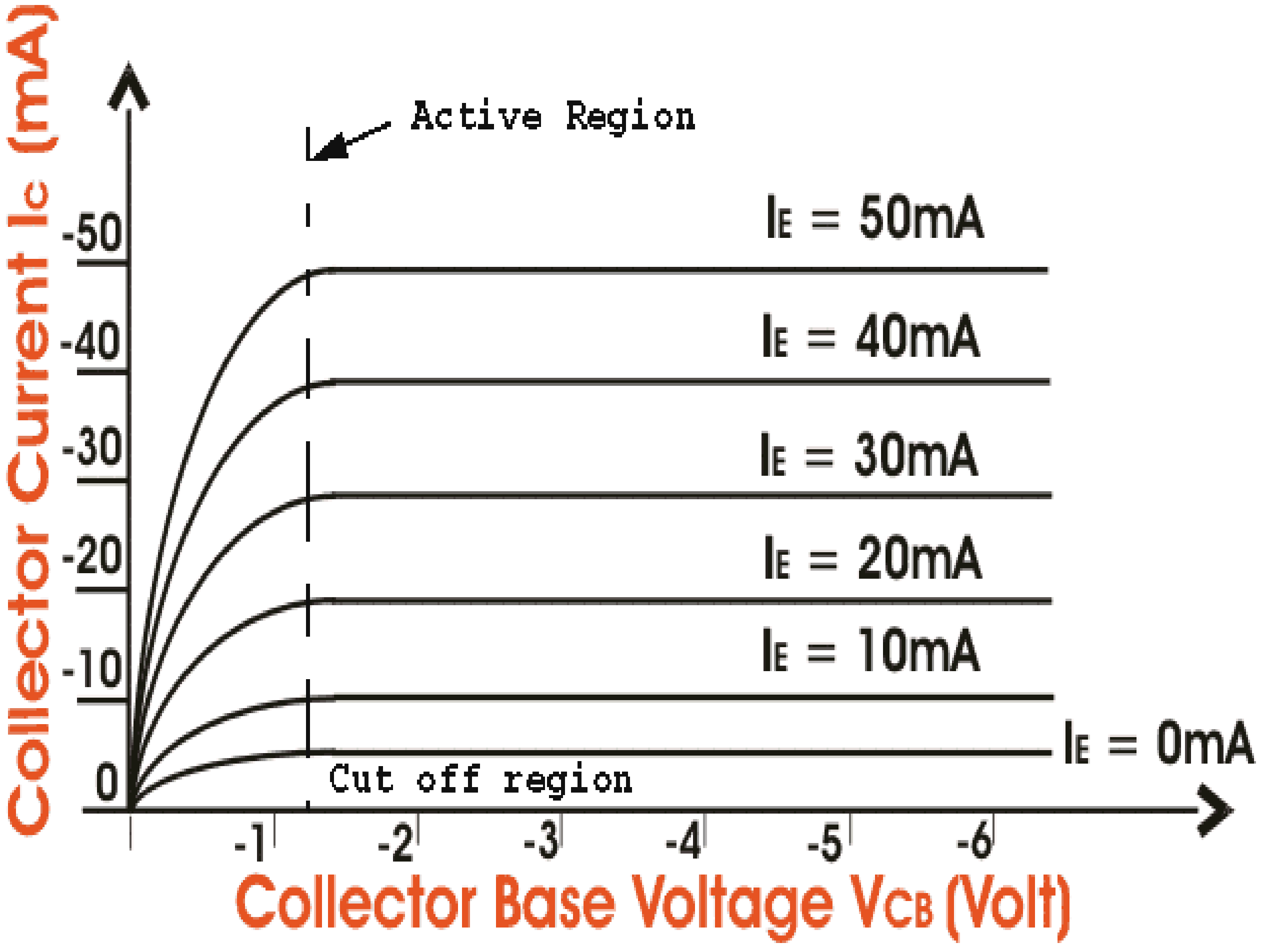
iii) Common collector Connection





Input characteristics

Output characteristics



2.5 Transistor biasing circuit

i) Emitter feedback bias

- An increasing in the collector current produces an increase in the voltage across the emitter resistor, which reduces the base current consequently the collector current.

- The emitter Resistor serves as the Feedback element. If we adding voltage as a collector then we get $\mathbf{V_{CE} + I_E R_E + I_c R_c - V_{CC} = 0}$

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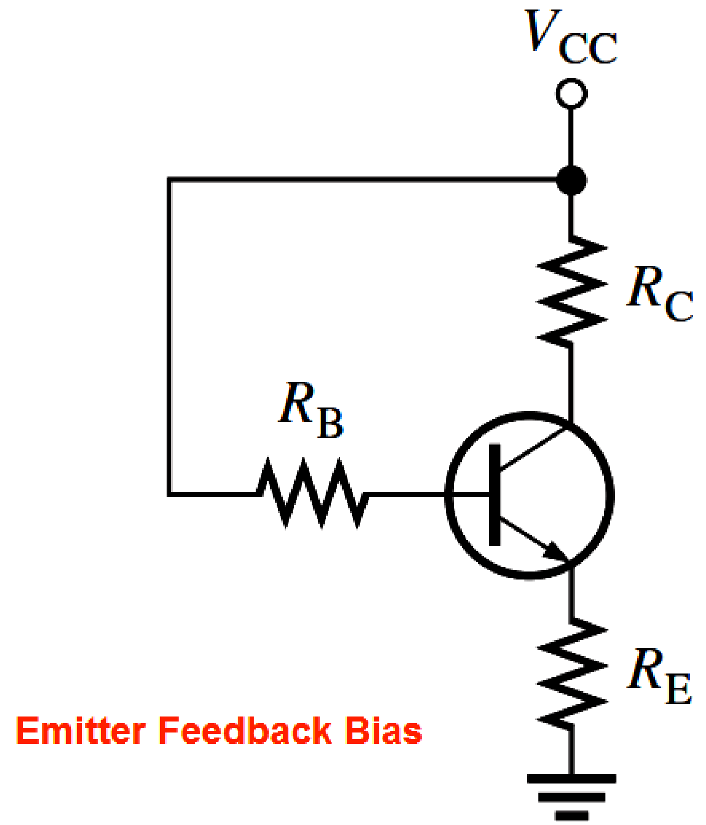


Since, $I_E \approx I_C$, we get

$$I_C \approx \frac{V_{CC} - V_{CE}}{R_C + R_E}$$

If we adding the voltages around the base loop, we get

$$I_E R_E + V_{BE} + I_B R_B - V_{CC} = 0$$

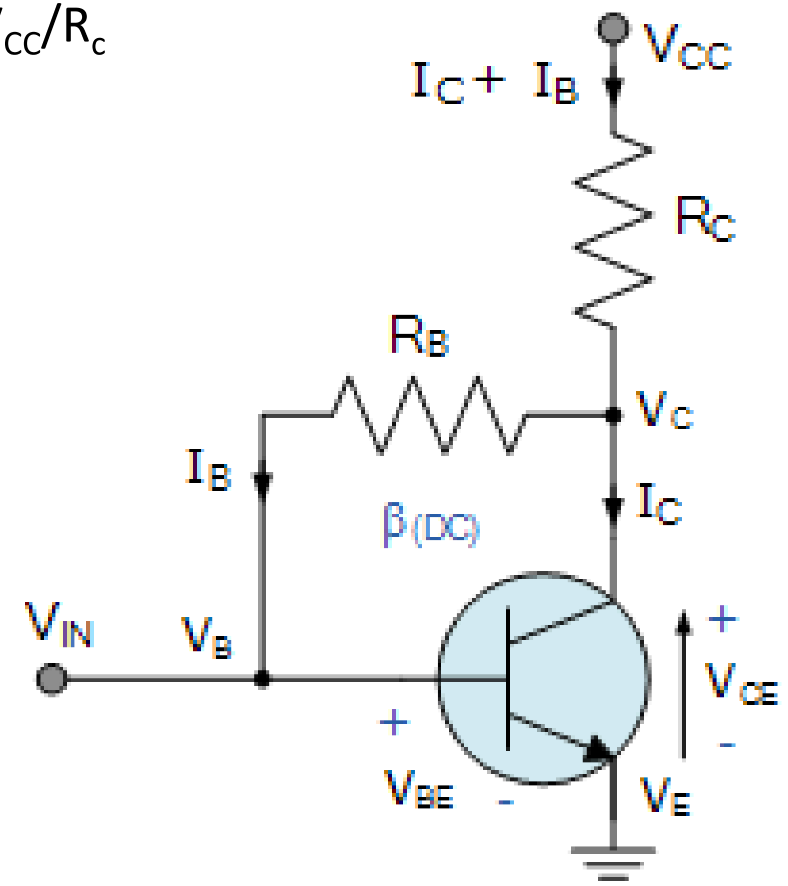
Since, $I_E \approx I_C$ and $I_B = \frac{I_C}{\beta_{DC}}$, we get

$$I_C = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}}$$

ii) Collector Feedback Bias (self Bias)

- This biasing method which requires two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β).

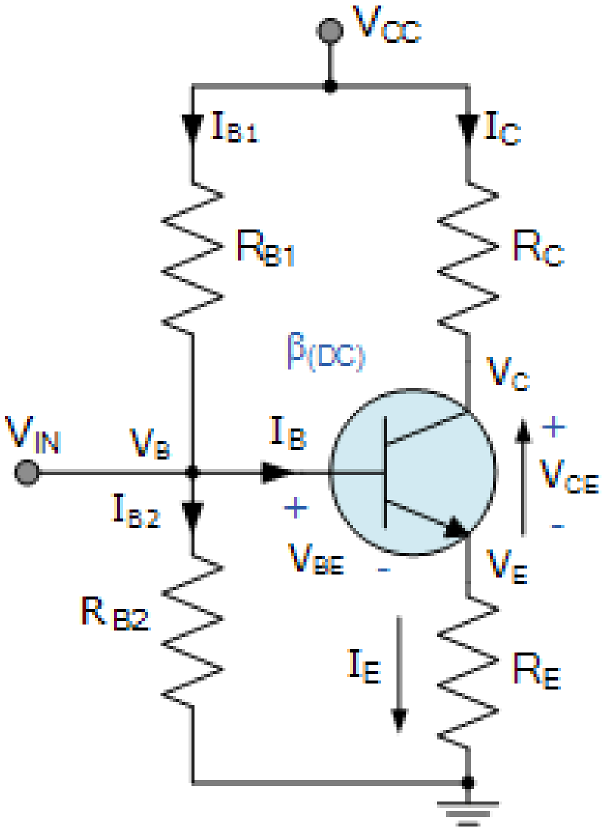
- The collector current which is less than V_{CC}/R_c , Hence the transistor can't be saturated.



$$V_C = V_{CC} - R_C(I_C + I_B)$$
$$V_E = 0v$$
$$V_B = V_{BE}$$
$$I_B = \frac{V_C - V_B}{R_B}$$
$$I_C = \beta_{(DC)} I_B$$
$$I_E = (I_C + I_B) \cong I_C$$

iii) Voltage Divider Bias

- The circuit known as voltage divider bias because of the voltage divider formed by $R_{B!}$ and R_{B2}.
- The voltage across R_{B2} forward biases the emitter diode.



$$V_C = V_{CC} - R_C I_C = (V_E + V_{CE})$$
$$V_E = I_E R_E = V_B - V_{BE}$$
$$V_{CE} = V_C - V_E = V_{CC} - (I_C R_C + I_E R_E)$$
$$V_B = V_{BE} + V_E = V_{RB2} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC}$$
$$I_{B2} = \frac{V_B}{R_{B2}}$$
$$I_{B1} = I_B + I_{B2} = \frac{V_{CC} - V_B}{R_{B1}}$$
$$R_B = \frac{R_{B1} \times R_{B2}}{R_{B1} + R_{B2}} \qquad I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta) R_E}$$
$$I_C = \beta_{(DC)} I_B$$
$$I_E = I_C + I_B = \frac{V_E}{R_E}$$

iv) Emitter Bias

If R_B is small enough, the base voltage is approximately zero. The voltage across emitter resister is V_{EE}-V_{BE} .

$$I_E \approx \frac{V_{EE} - V_{BE}}{R_E}$$

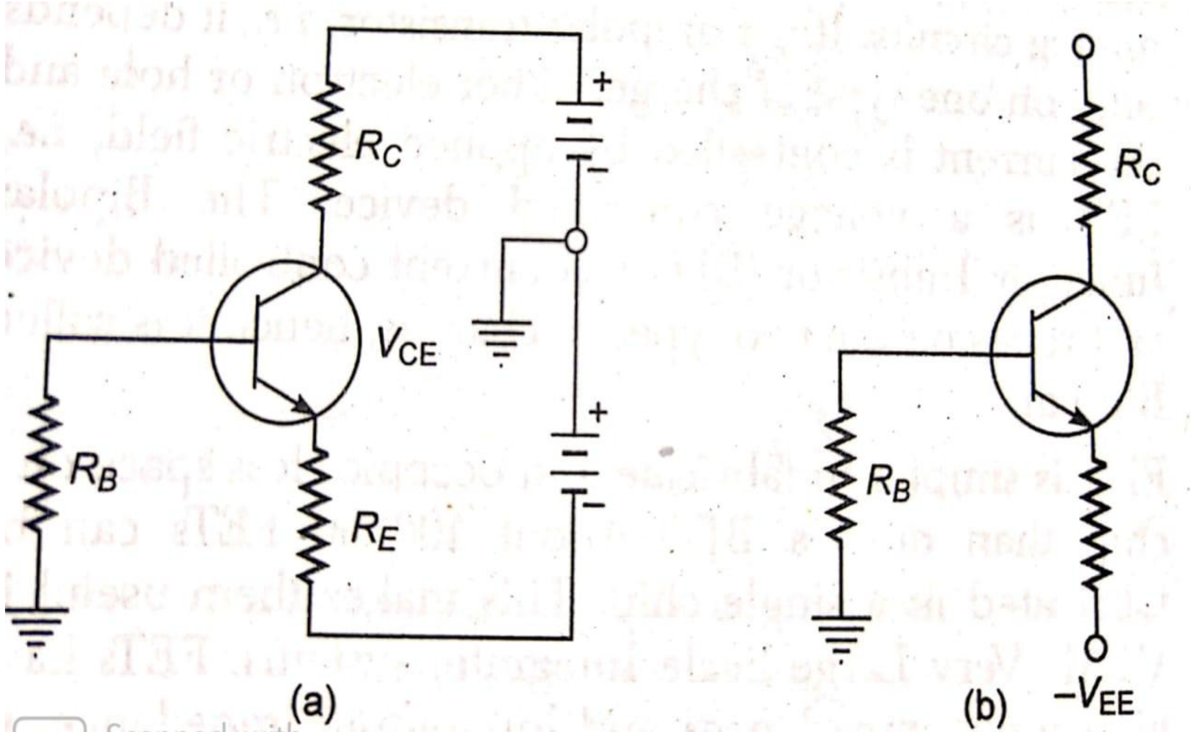
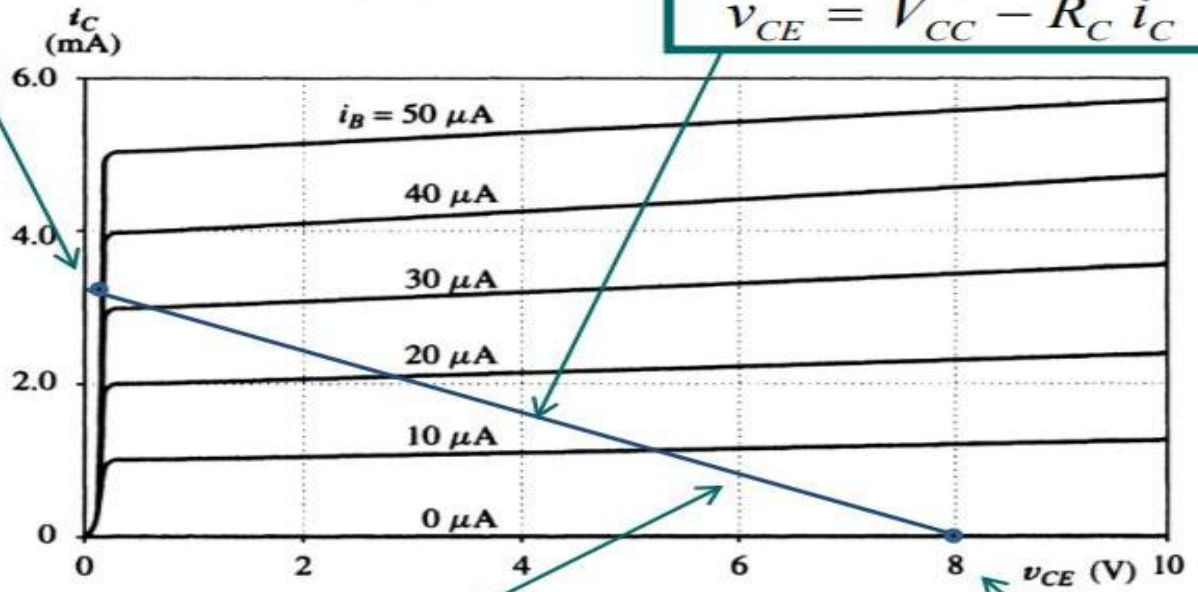


Fig. (a) Emitter bias circuit (b) Equivalent circuit

2.6 BJT Transfer Function on the Load line

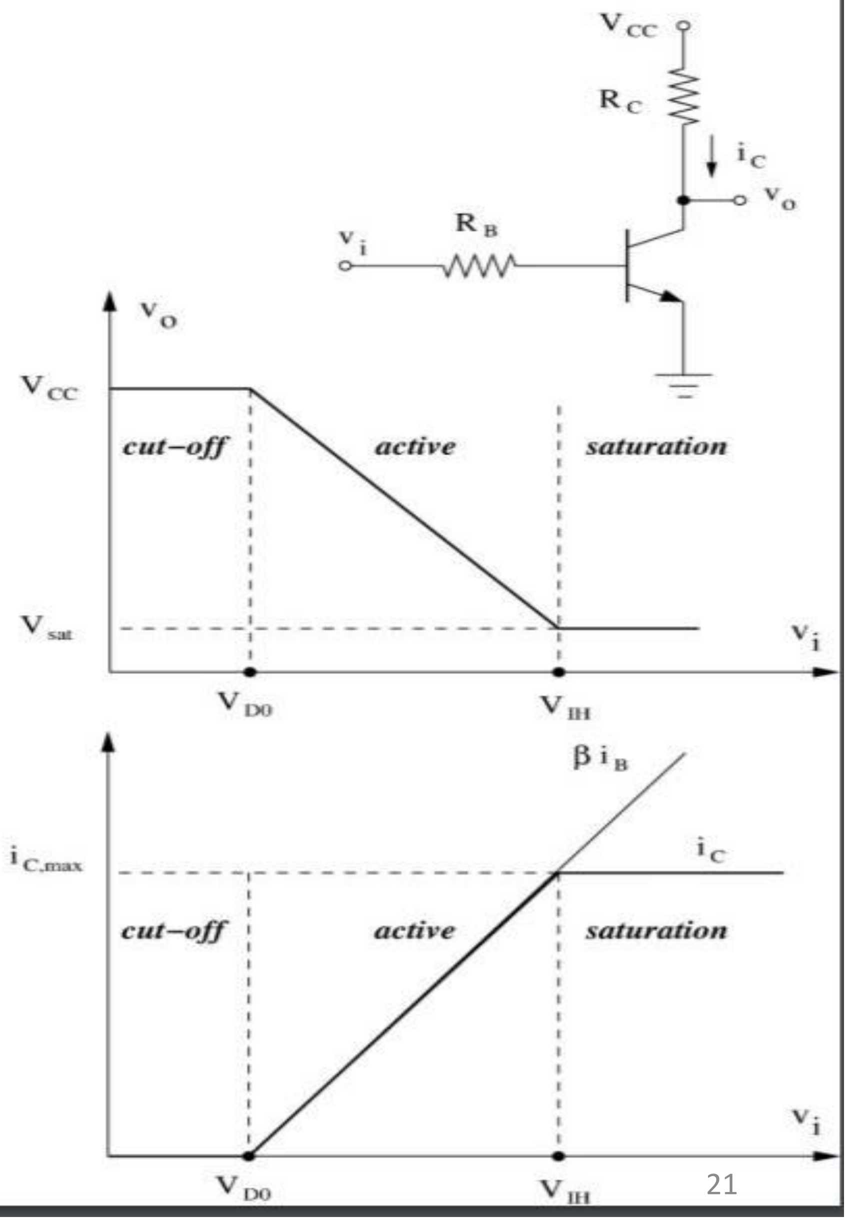
Saturation : $V_{IH} < v_i$
i_B increases but i_C unchanged

Load Line (CE - KVL)
$v_{CE} = V_{CC} - R_C \, i_C$



Active : $V_{D0} \le v_i \le V_{IH}$
i_B & i_C increase together

Cut – off :
$v_i < V_{D0}$



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