

Bipolar Junction Transistor (BJT)

- Beside diodes, the most popular semiconductor devices is transistors. Eg: Bipolar Junction Transistor (BJT)
- Few most important applications of transistor are: as an amplifier, as an oscillator and as a switch.
- Amplification can make weak signal strong in general, provide function called Gain
- BJT is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device

N-type regions contains free electrons (negative carriers)

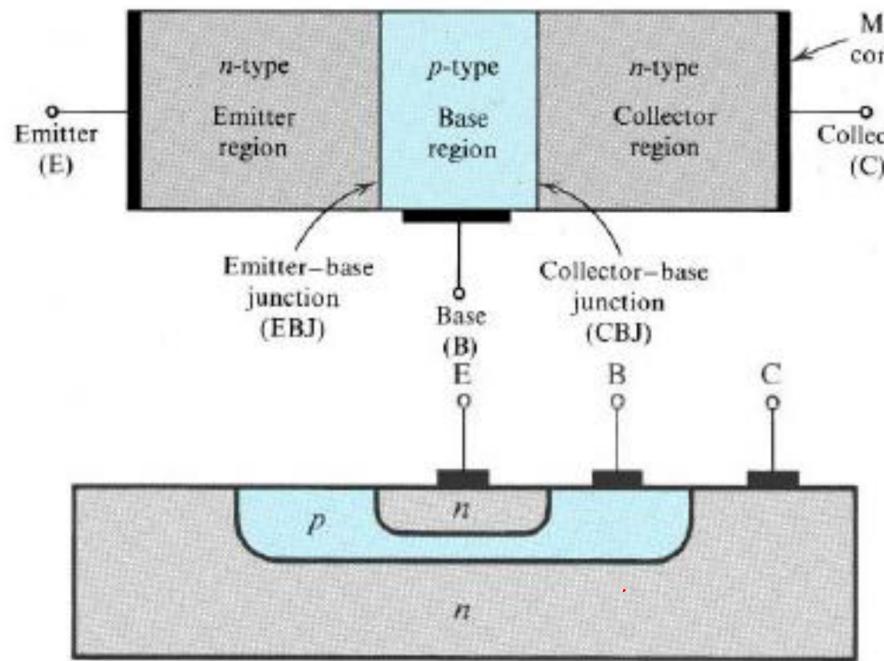
P-type regions contains free holes (positive carriers)



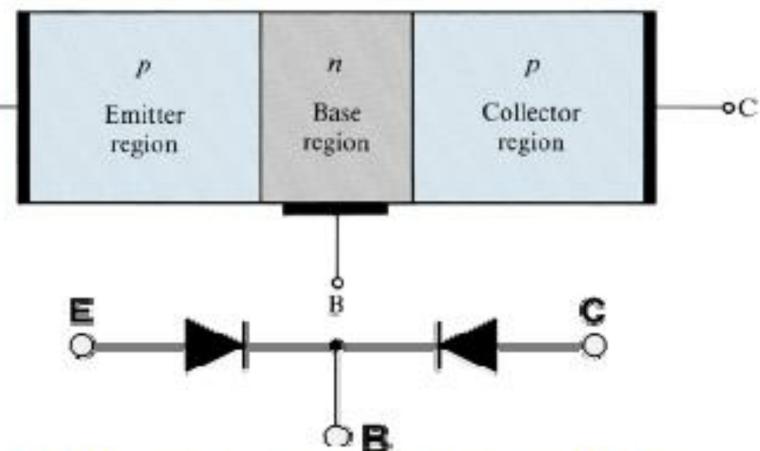
- The word Transistor is an acronym, and is a combination of the words **Transfer Varistor** used to describe their mode of operation way back in their early days of development. There are two basic types of bipolar transistor construction, NPN and PNP, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.

Bipolar Junction Transistor (BJT)

npnTransistor



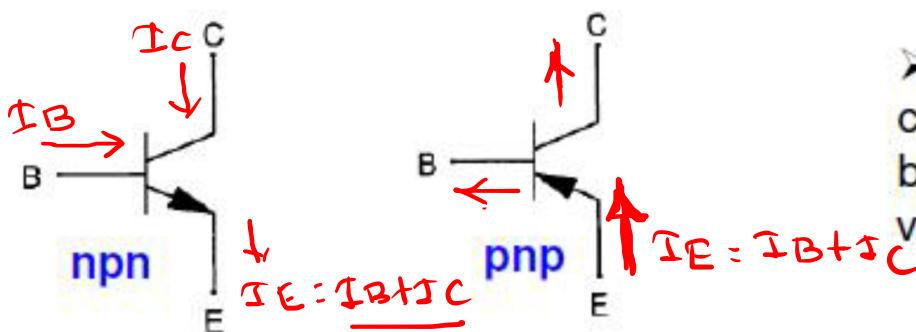
pnpTransistor



➤ BJT is a 3 terminal device. namely- emitter, base and collector

➤ npn transistor: emitter & collector are n-doped and base is p-doped.

➤ Emitter is heavily doped, collector is moderately doped and base is lightly doped and base is very thin. i.e. $N_{DE} \gg N_{DC} \gg N_{AB}$

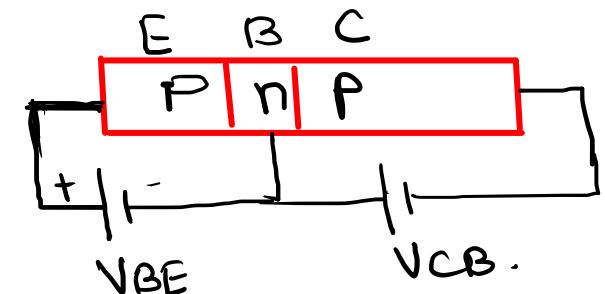
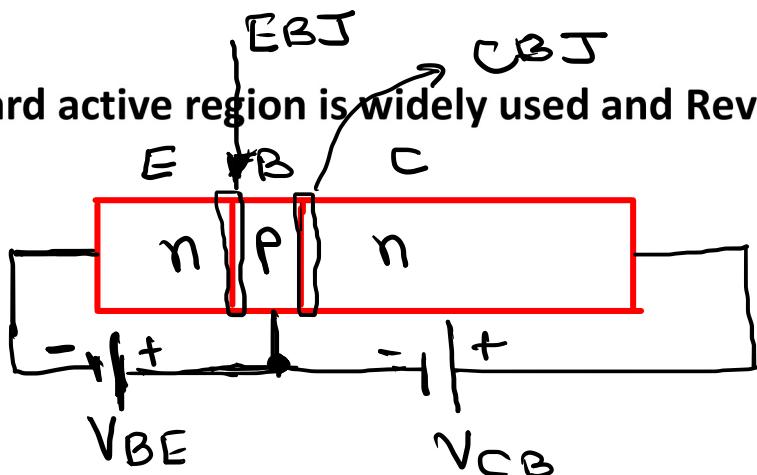


Mode of operation for BJT

Mode	V_{BE}	V_{BC}	
⇒ Forward active	Forward bias	Reverse Bias	Amplifier/ oscillator
✗ Reverse active	Reverse Bias	Forward Bias	
Saturation	Forward bias	Forward bias	
Cut off	Reverse Bias	Reverse Bias	BJT as switch

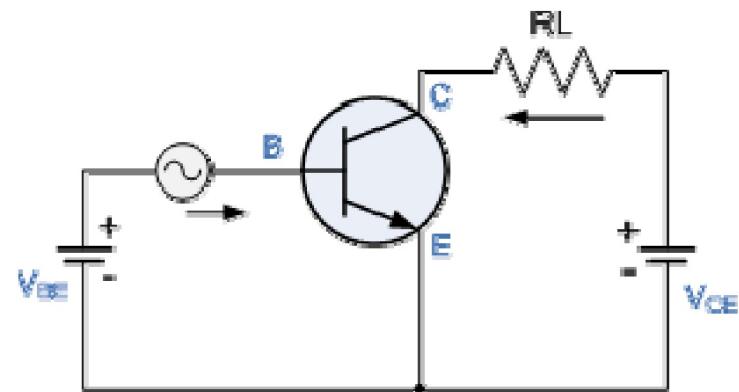
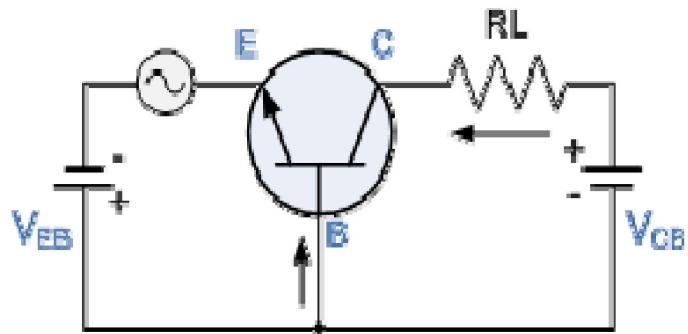
- Forward active region is widely used and Reverse active region is rarely used

⇒ Forward Active mode



Different configuration of BJT

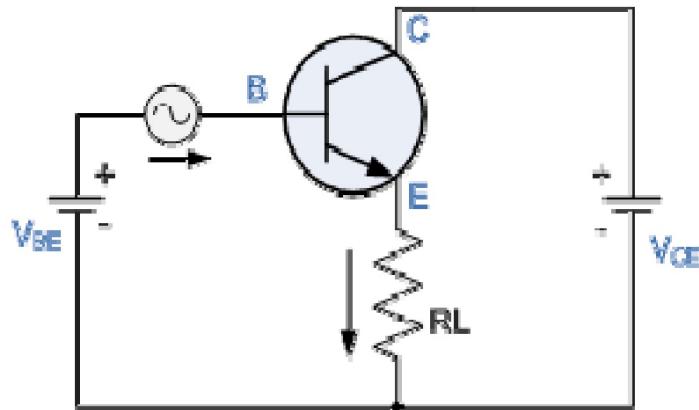
Common base configuration



Non-inverting voltage amplifier circuit

Common emitter configuration

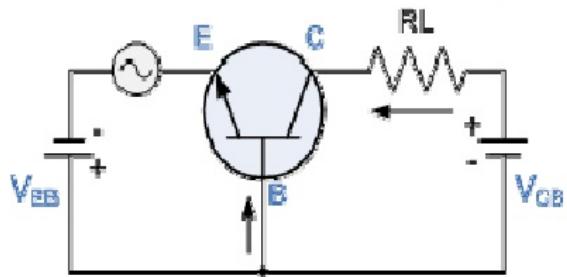
Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

Configurations of BJT

① Common base configuration



Non-inverting voltage amplifier circuit

Output current (I_C)

Input current (I_E)

$$\text{Current gain} (\alpha) = \frac{I_C}{I_E}$$

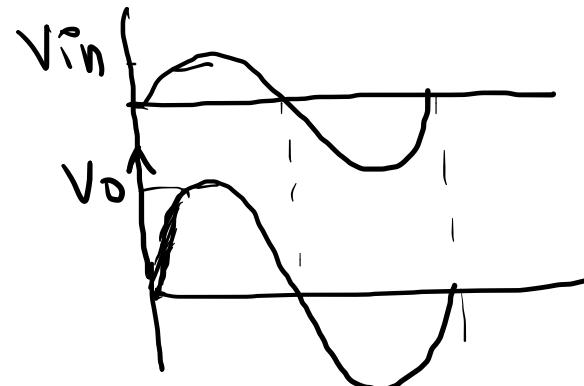
$\Rightarrow \alpha \leq 1$ so current gain is less than one.

\Rightarrow High voltage gain

\Rightarrow Voltage amplifier

\Rightarrow Non-inverting Amplifiers

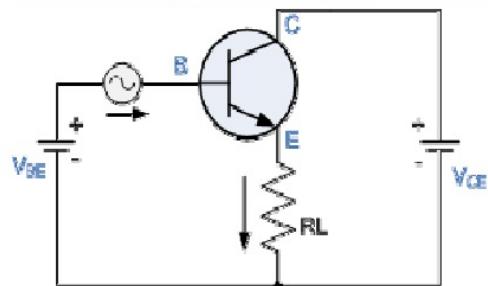
\Rightarrow Very high Bandwidth



Configurations of BJT

11

Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

Input current base current (I_B)

Output current (I_E)

$$\text{Current gain} = \frac{I_E}{I_B} > 1$$

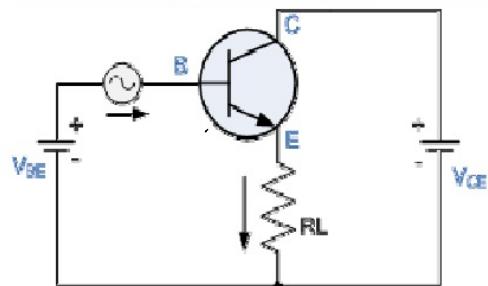
Voltage gain $\beta_s = 1$.

To increase current on load \Rightarrow Current Buffer circuit

Configurations of BJT

11

Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

Input current base current (I_B)

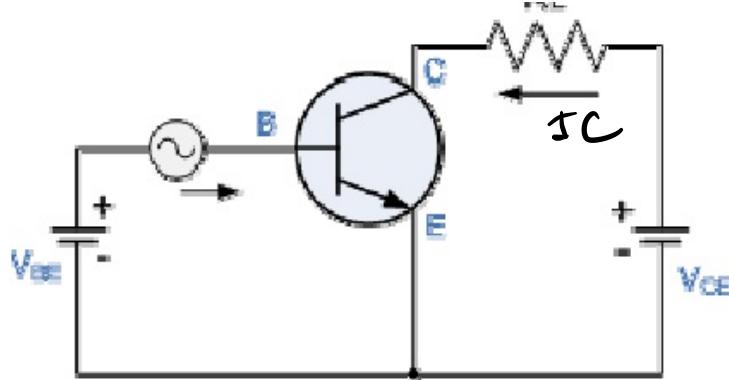
Output current (I_E)

$$\text{Current gain} = \frac{I_E}{I_B} > 1$$

Voltage gain $\beta_s = 1$.

To increase current on load \Rightarrow Current Buffer circuit

③



⇒ Voltage gain is high

⇒ Suitable for Power Amplifiers

Common emitter configuration

Input Current = I_B

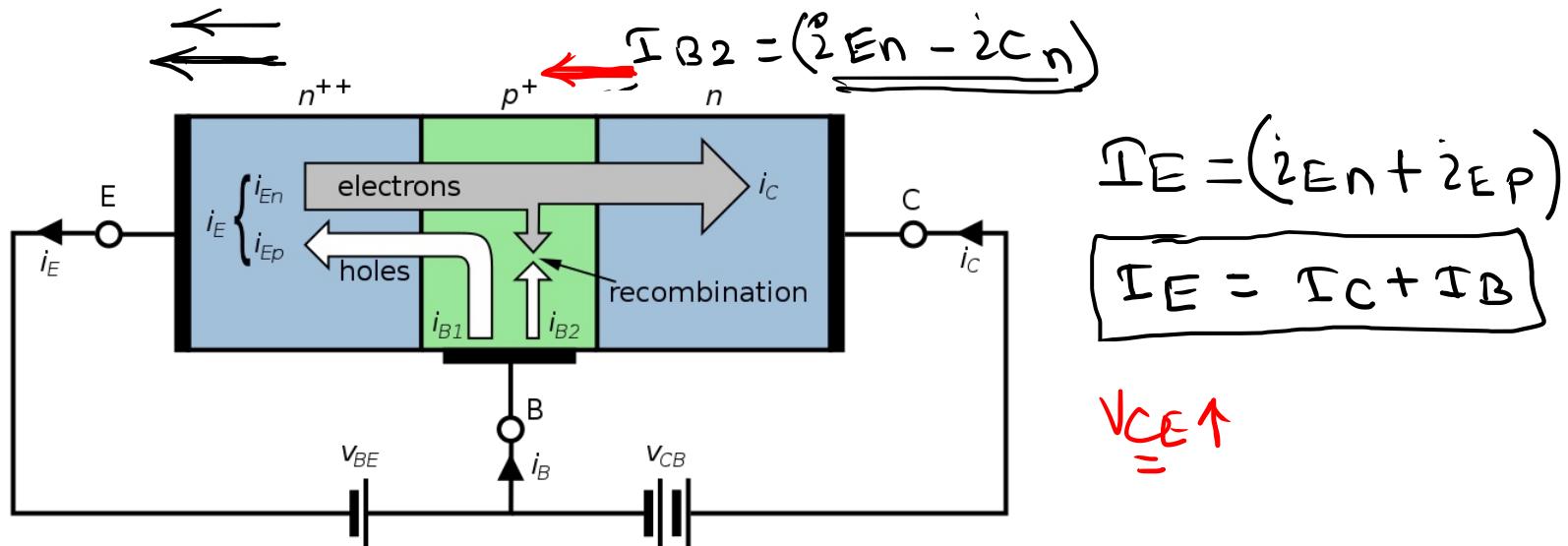
Output Current = I_C

Current gain = $\frac{I_C}{I_B} = \beta$

$I_C \gg I_B$

$(\beta) \gg 1$

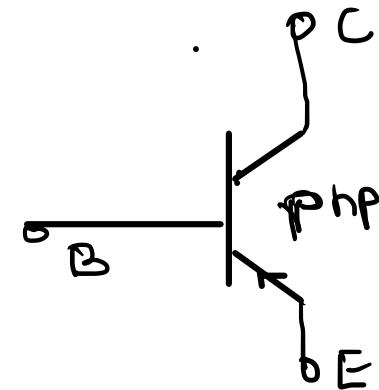
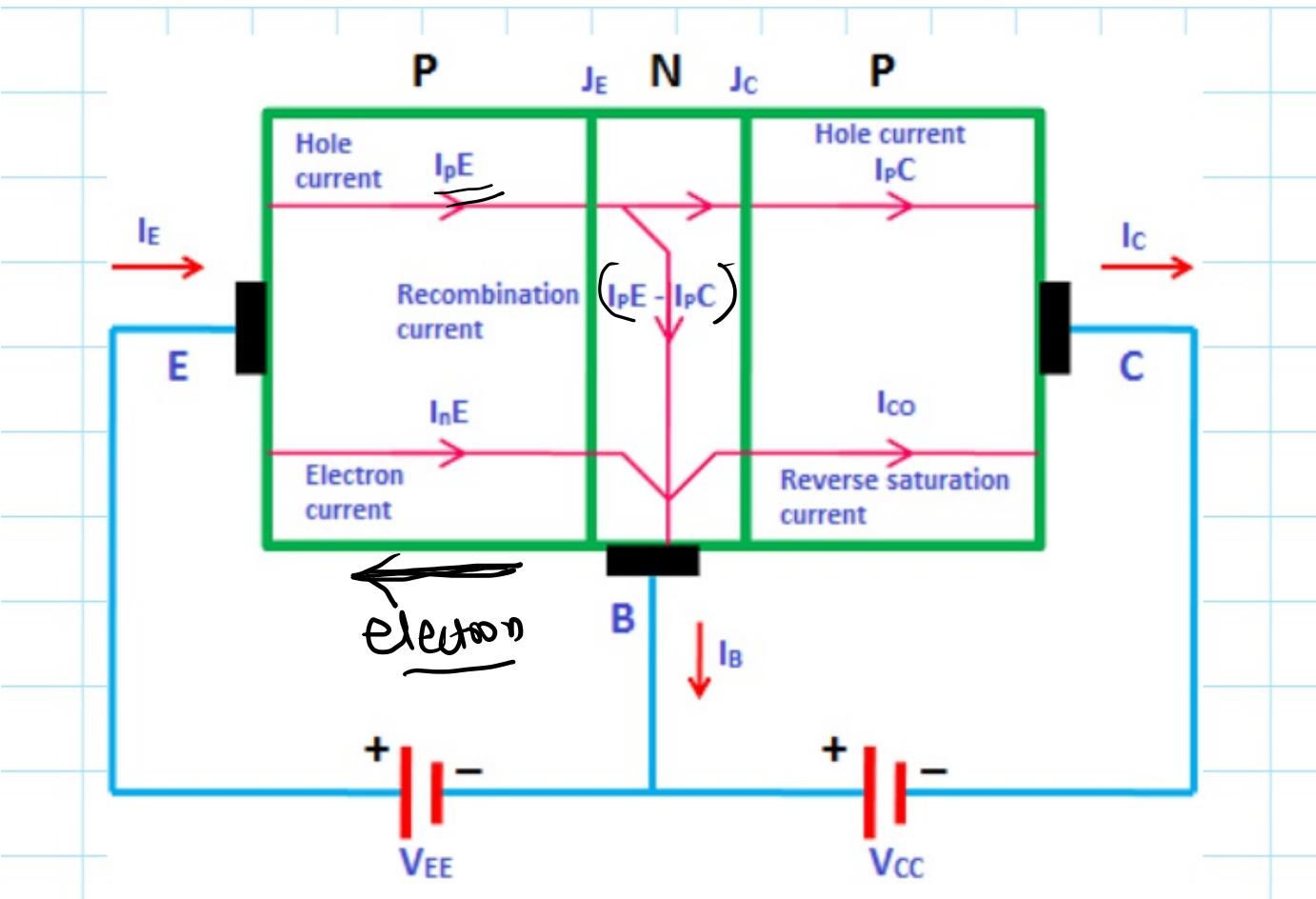
DC operation of npn BJT under forward active mode



- 1 . Forward bias of EBJ causes electrons to diffuse from emitter into base.
- 2. As base region is very thin, the majority of these electrons diffuse to the edge of the depletion region of CBJ, and then are swept to the collector by the electric field of the reverse-biased CBJ.
- 3. A small fraction of these electrons recombine with the holes in base region.
- 4. Holes are injected from base to emitter region. (4) << (1).

- The two-carrier flow from [(1) and (4)] forms the emitter current (I_E).

DC operation of npn BJT under forward active mode



⇒ Relation betn DC Currents & gains

$$I_E = I_C + I_B.$$

$$\alpha = \frac{I_C}{I_E}$$

$$\beta = \frac{I_C}{I_B}.$$

$$I_C = \alpha I_E$$

$$\beta = \frac{I_C}{I_E(1-\alpha)}$$

$$\beta = \frac{\alpha I_E}{(1-\alpha) \cdot I_E}$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

$$I_E = \alpha I_E + I_B.$$

$$I_B = I_E(1-\alpha)$$

$$\frac{I_C}{\beta} = I_E(1-\alpha)$$

Current Relations (CE)

$$\textcircled{1} \rightarrow I_B + I_C = I_E \quad \checkmark$$

$$I_C \stackrel{\text{def}}{=} \beta I_E \quad \checkmark$$

$$I_C = \alpha I_E \quad \stackrel{?}{=}$$

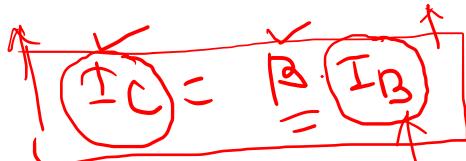
$\hookrightarrow I_B + \alpha I_E = I_E$

$$I_B = (1 - \alpha) I_E$$

$$I_B = (1 - \alpha) \frac{I_E}{\alpha}$$

$$I_B = \frac{(1 - \alpha)}{\alpha} I_C$$

$$I_C = \left(\frac{\alpha}{1 - \alpha} \right) I_B \quad \checkmark$$



β = current gain of BJT

$$\beta \Rightarrow \underline{50} \text{ to } \underline{400} \quad \underline{=}$$

$$I_B + \beta I_B = I_E$$

$$I_E = (\beta + 1) I_B$$

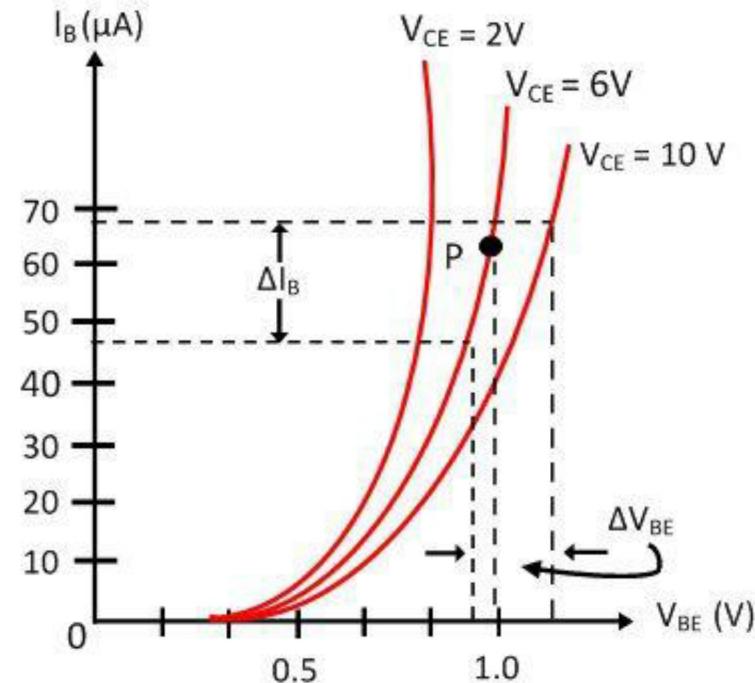
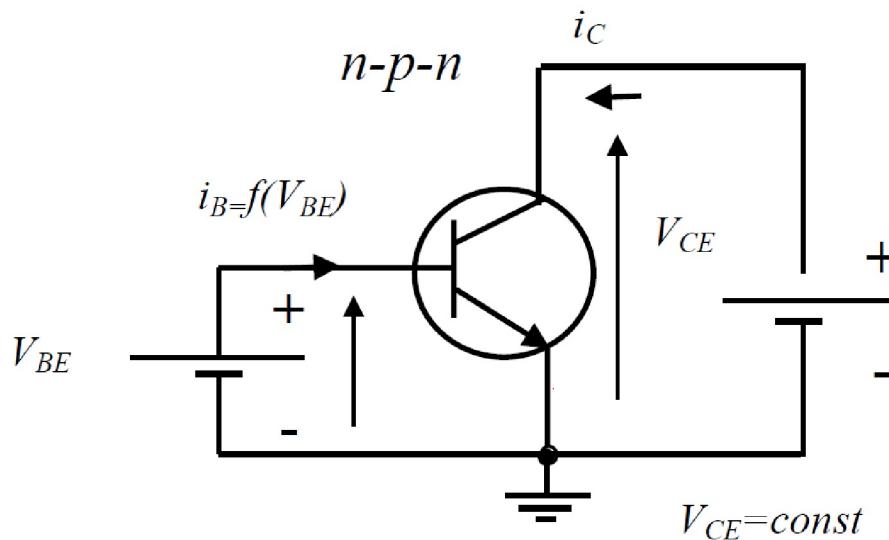
$$I_C = \beta I_B$$

$I_C = \beta I_B$

BJT is current controlled device.

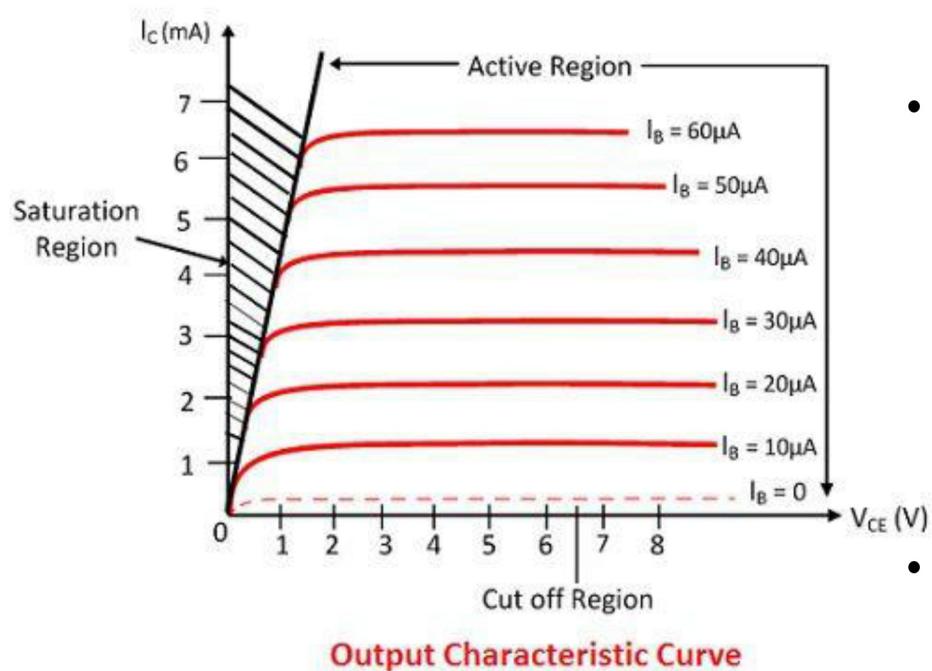
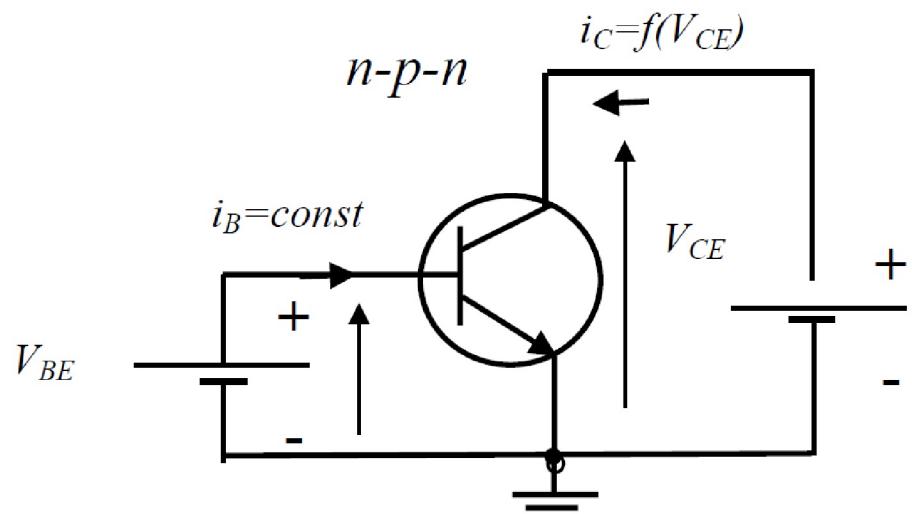
FET \Rightarrow voltage controlled device

⇒ Input characteristics of BJT in Common Emitter configuration



- Input characteristics are like a normal forward biased diode. As V_{BE} increased I_B also increased.
- $i_B(V_{BE})$ can be approximated as a step function at $V_{BE} \approx 0.7\text{V}$
- **Input Resistance:** The ratio of change in base-emitter voltage V_{BE} to the change in base current ΔI_B at constant collector-emitter voltage V_{CE} is known as input resistance, i.e.,
$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

Output characteristics of BJT in CE configuration



- In the active region, the collector current increases slightly as collector-emitter VCE current increases. The slope of the curve is quite more than the output characteristic of CB configuration. Active region: i_C is a weak function of V_{CE}
- - The value of the collector current i_C increases with the increase in V_{CE} at constant ~~i_B~~ i_B , the value β of also increases.
 - When the V_{CE} falls, the i_C also decreases rapidly. The collector-base junction of the transistor always in forward bias. In the saturation region, the collector current becomes independent and free from the input current i_B . Saturation region: $V_{CE} < 0.5V$
 - In the active region $i_C = \beta i_B$, a small current i_C is not zero, and it is equal to reverse leakage current i_{CEO} .

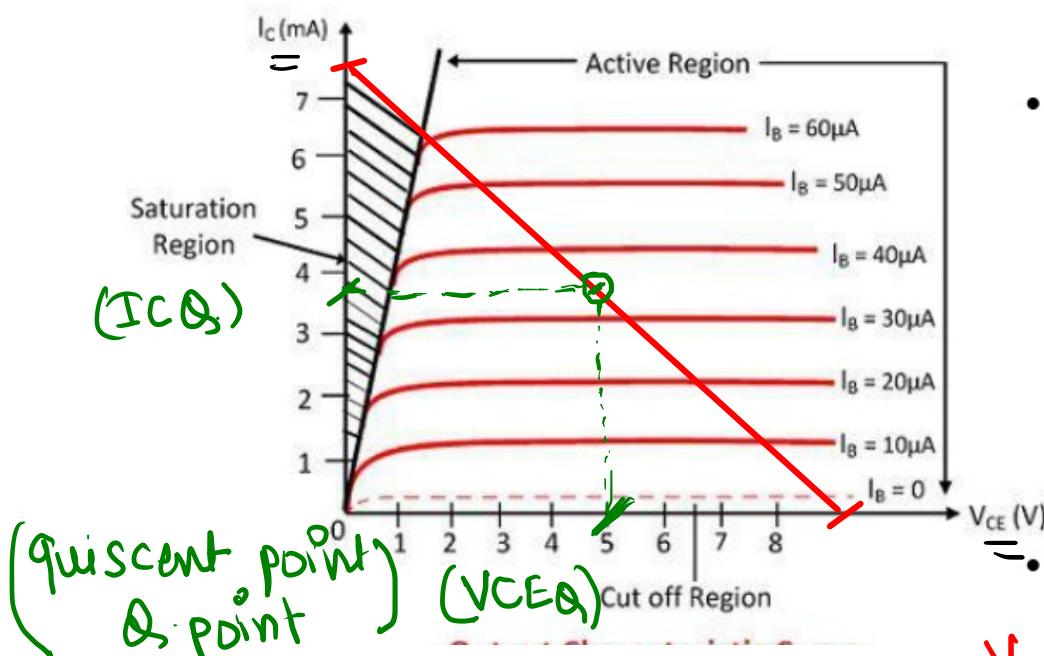
Biassing of Transistor

Transistor Operation regions:

Region of operation	Emitter Base Junction	Collector - Base Junction
Cut-off	Reverse Bias	Reverse Bias
→ Active	Forward Bias	Reverse Bias
Saturation	Forward Bias	Forward Bias

1. In order to operate transistor in desired region, external DC voltage (Bias) of correct polarity is applied to the two junctions of transistor.
2. With biasing a certain current and voltage conditions is established, called as DC operating or quiscent point.
3. Operating Point may shift because of changes in transistor parameters such as *Beta*, I_{CO} , and V_{BE} .
4. *Beta*, I_{CO} , and V_{BE} are *temperature dependent*.

⇒ Need of Biasing

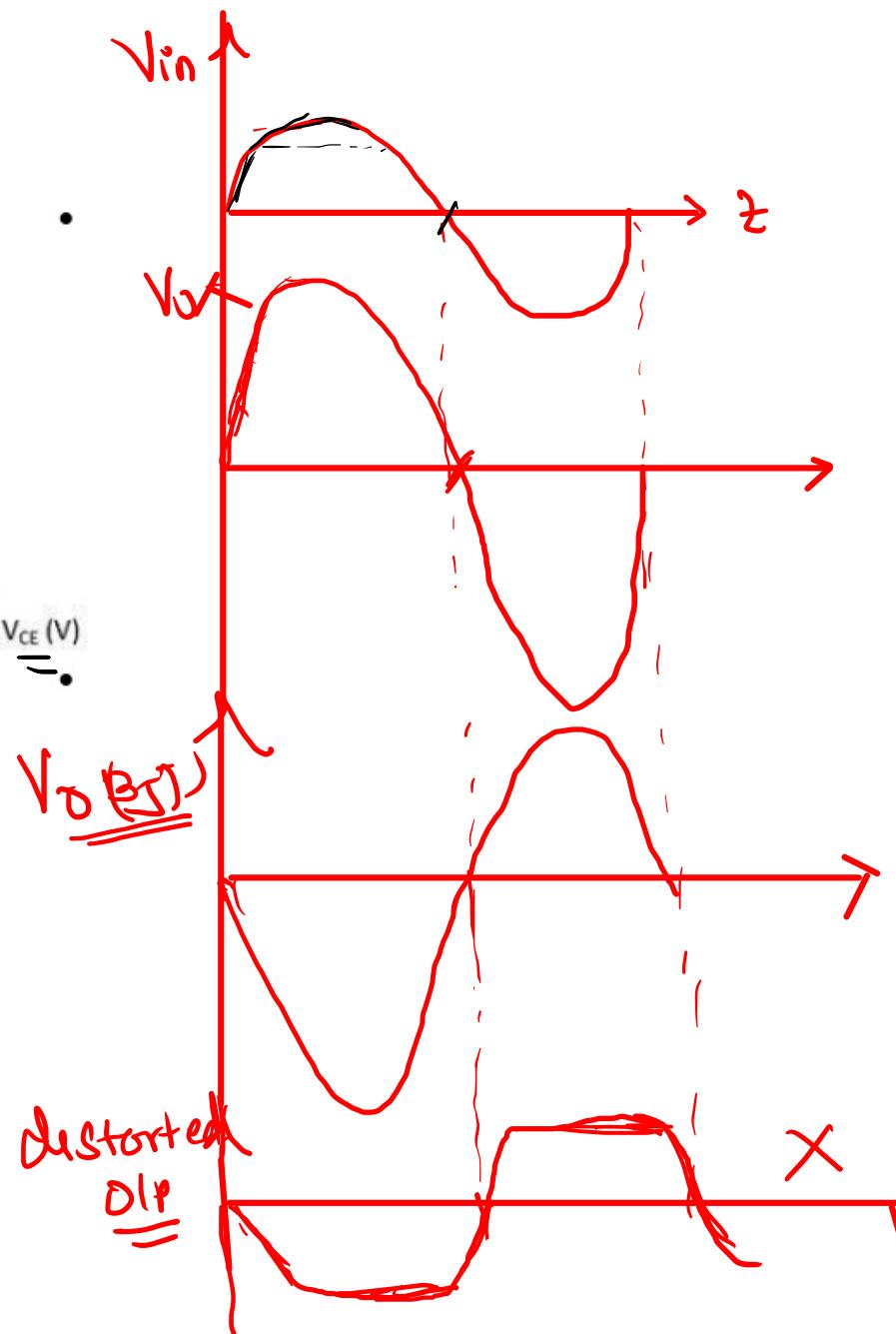


(quiescent point)

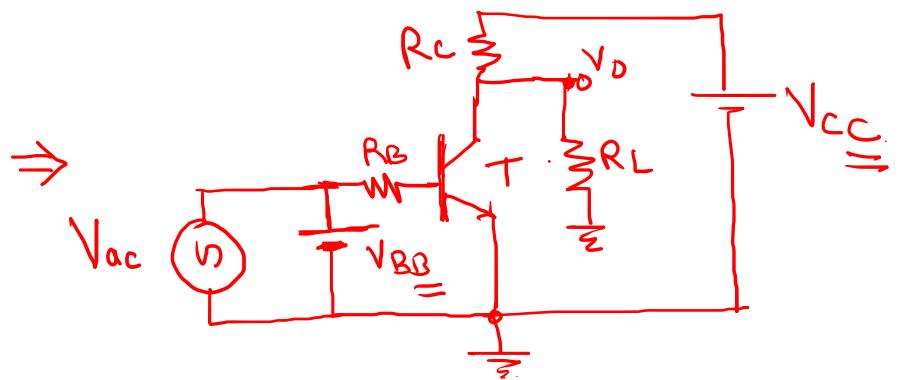
$\&$ point

✓ ① Biasing \Rightarrow EBJ FB
CBJ - R_B

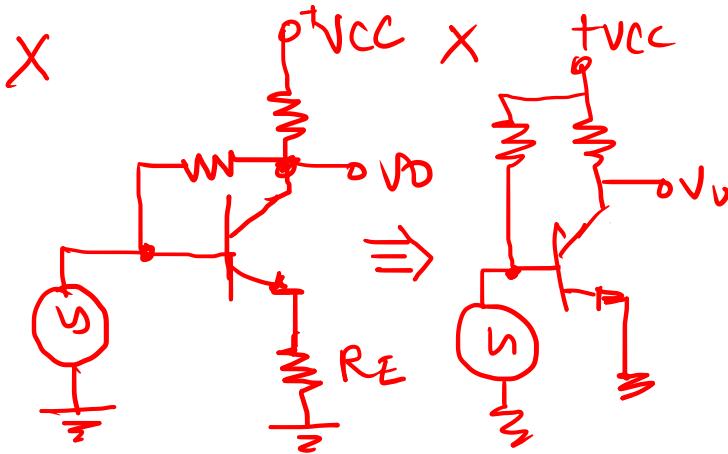
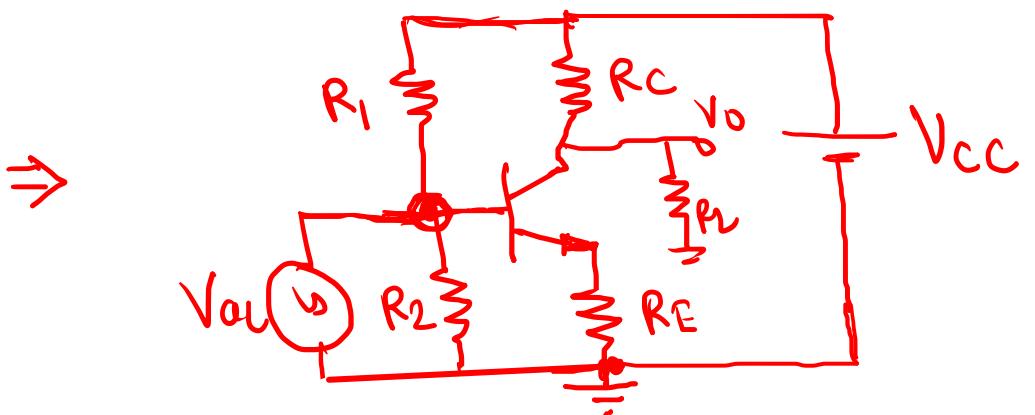
② Output must be distortion free



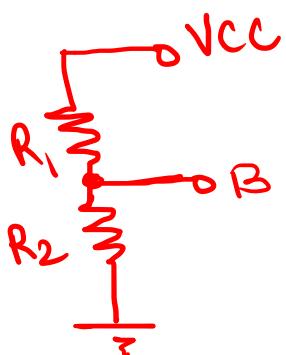
⇒ Voltage Divider Bias



⇒ Two DC Supply (V_{BB}) & V_{CC} to ensure
Active mode [$E_{BJ} \Leftrightarrow F_B$
 $C_{BJ} \Rightarrow R_B$.]

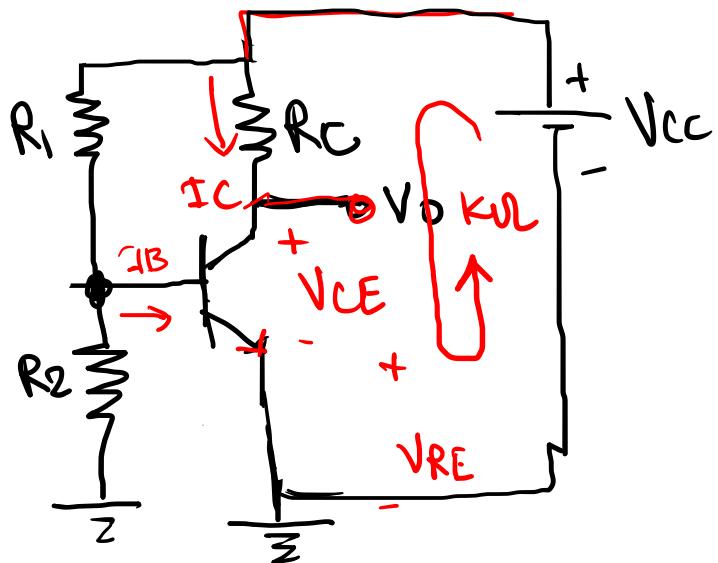


Voltage divider bias



$$V_{BB} = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$

⇒ CE Amplifier & load line.

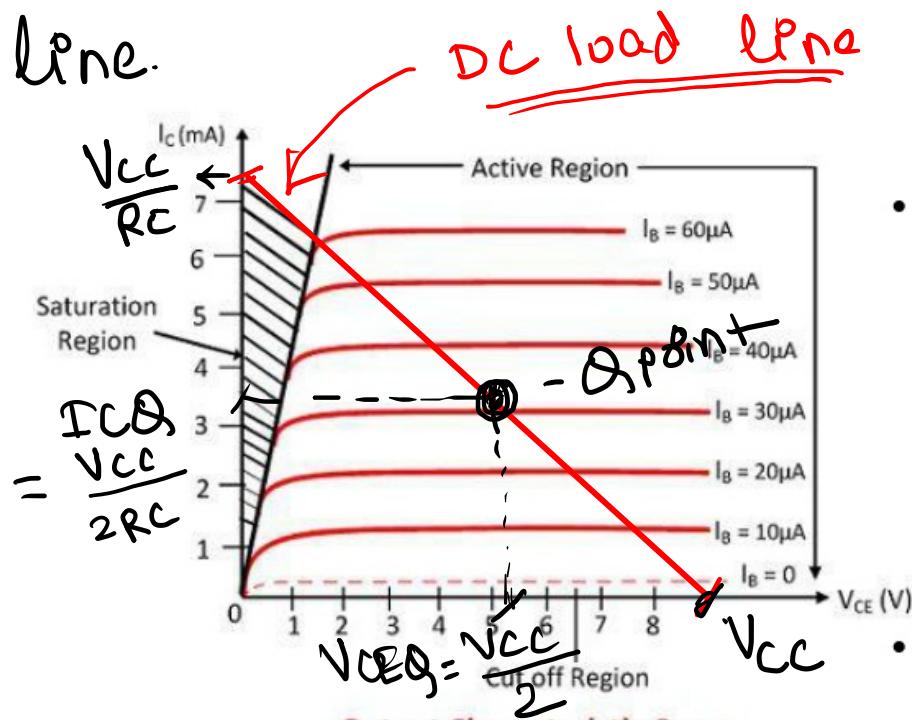


⇒ DC conditions.

Applying KVL to collector/op side

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_O = V_{CE} = V_{CC} - I_C R_C \quad \boxed{①}$$



in equation ①

$$I_C = 0$$

$$V_{CE} = V_{CC}$$

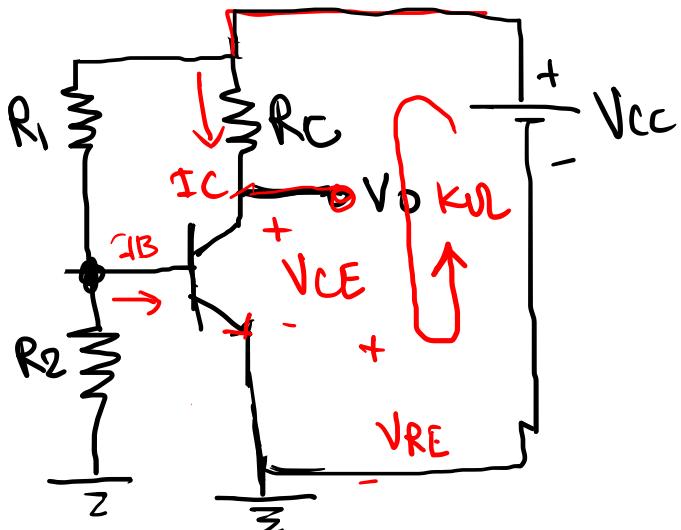
Cutoff region

$$V_{CE} = 0$$

$$I_C = \frac{V_{CC}}{R_C}$$

Saturation region

⇒ CE Amplifier & load line.

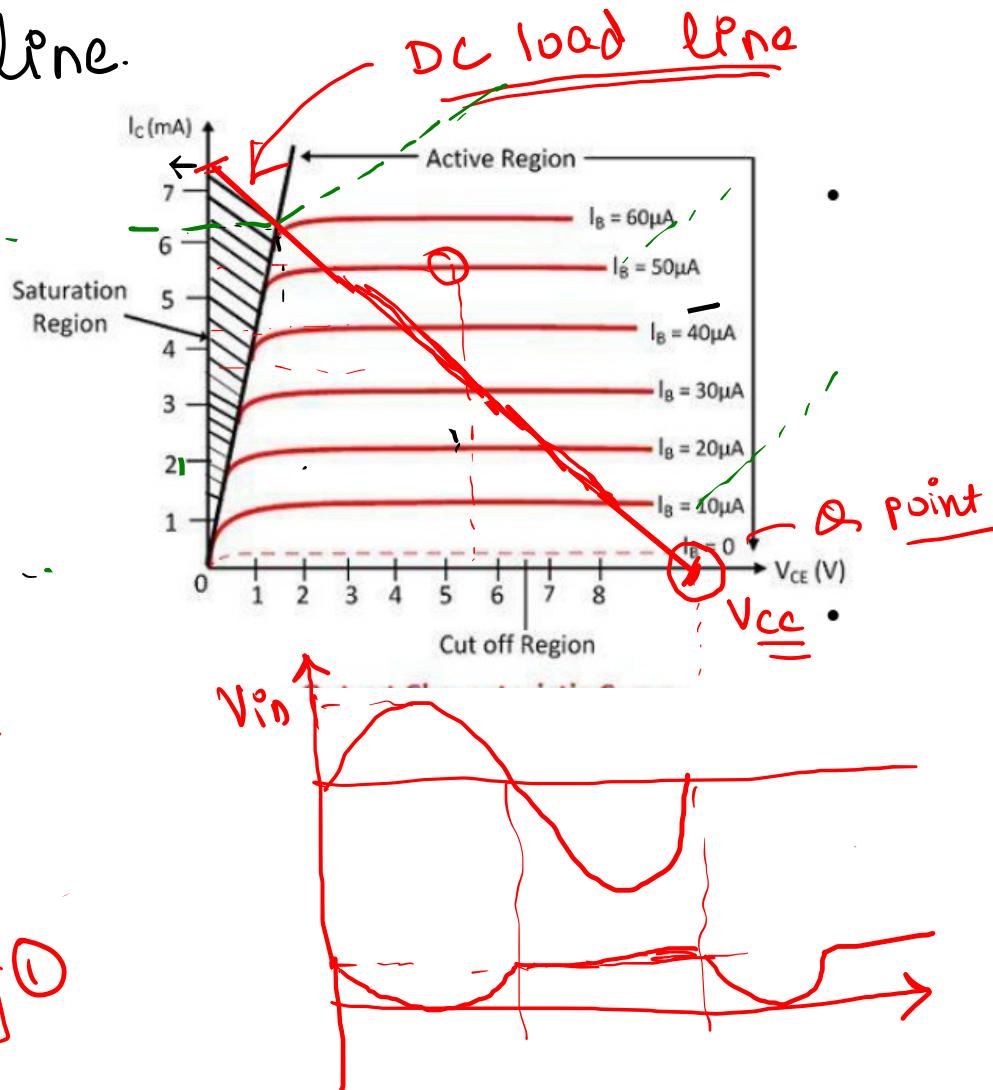


⇒ DC conditions.

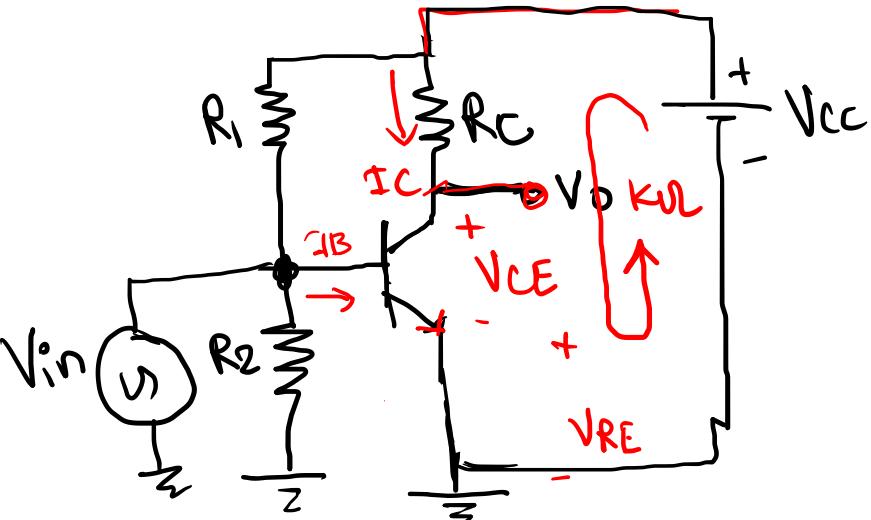
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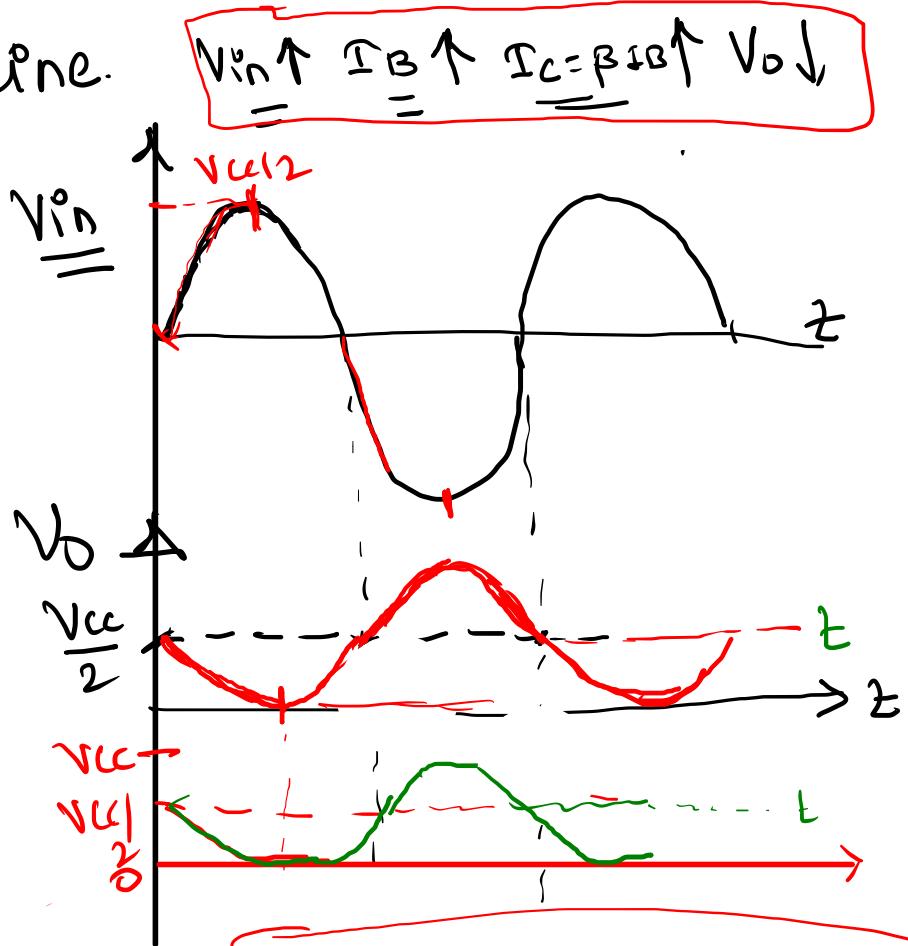


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Applying KVL to collector/op side

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⇒ Class - A operation
 ⇒ Class - B Class - C
 ⇒ Class - AB

Stability of operating POINT

--> Degree of change of operating point with temperature

$$\textcircled{1} \quad S = \frac{\Delta I_C}{\Delta I_{C0}} \quad | \quad \begin{matrix} V_{BE} & \neq \\ \hline & = \\ \hline \end{matrix} \quad \begin{matrix} \beta & \text{Constant} \\ \hline & = \\ \hline \end{matrix}$$

OR

$$S = \frac{\partial I_C}{\partial I_{C0}}$$

$$\textcircled{2} \quad S' = \frac{\Delta I_C}{\Delta V_{BE}} \quad | \quad \begin{matrix} I_{C0} & \neq \\ \hline & = \\ \hline \end{matrix} \quad \begin{matrix} \beta & \text{Constant} \\ \hline & = \\ \hline \end{matrix}$$

$$S' = \frac{\partial I_C}{\partial V_{BE}}$$

$$\textcircled{3} \quad S'' = \frac{\Delta I_C}{\Delta \beta} \quad | \quad \begin{matrix} I_{C0} & \neq \\ \hline & = \\ \hline \end{matrix} \quad \begin{matrix} V_{BE} & \text{Constant} \\ \hline & = \\ \hline \end{matrix} \rightarrow S'' = \frac{\partial I_C}{\partial \beta}$$

Stability factor (S) for Common Emitter (CE) Configuration

$$\Rightarrow S = \frac{\partial I_C}{\partial I_{C0}}$$

$$I_C = \beta I_B + I_{CEO}$$

$$\checkmark I_C = \beta I_B + (\beta + 1) I_{CB0}$$

DIFF. wrt. I_C

$$I = \beta \times \frac{\partial I_B}{\partial I_C} + (\beta + 1) \frac{\partial I_{CB0}}{\partial I_C}$$

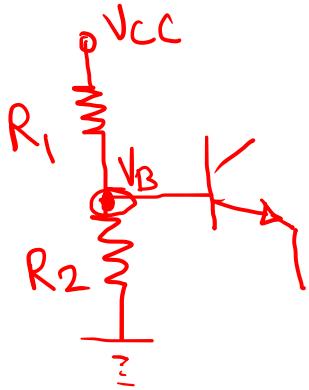
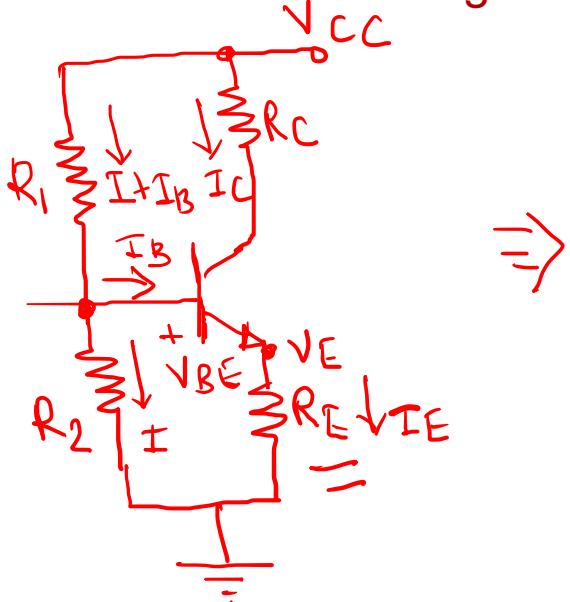
$$I = \beta \times \frac{\partial I_B}{\partial I_C} + \beta \cdot \frac{\partial I_{CB0}}{\partial I_C} + \frac{\partial I_{CB0}}{\partial I_C}$$

$$1 - \beta \frac{\partial I_B}{\partial I_C} = (\beta + 1) \frac{\partial I_{CB0}}{\partial I_C}$$

$$\frac{\partial I_{CB0}}{\partial I_C} = \frac{1 - \beta \cdot \frac{\partial I_B}{\partial I_C}}{1 + \beta}$$

$$S = \frac{1 + \beta}{1 - \beta \cdot \frac{\partial I_B}{\partial I_C}}$$

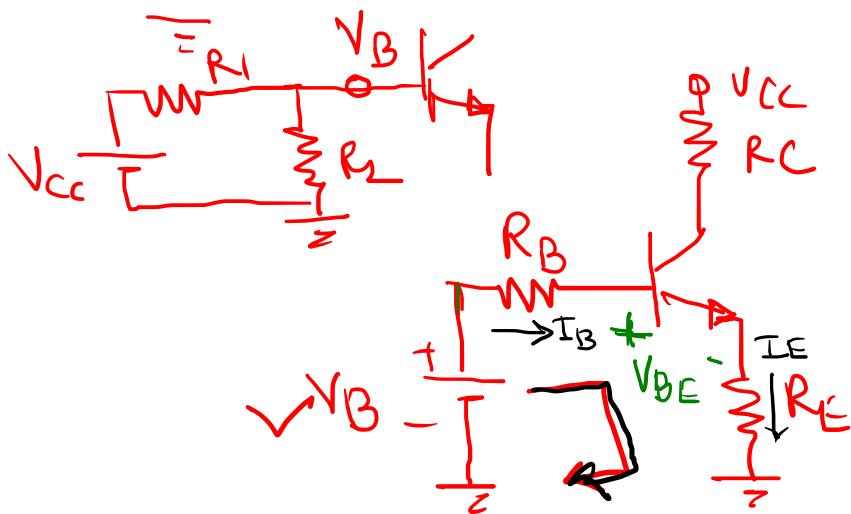
Voltage divider or self bias circuits



USING voltage division formula

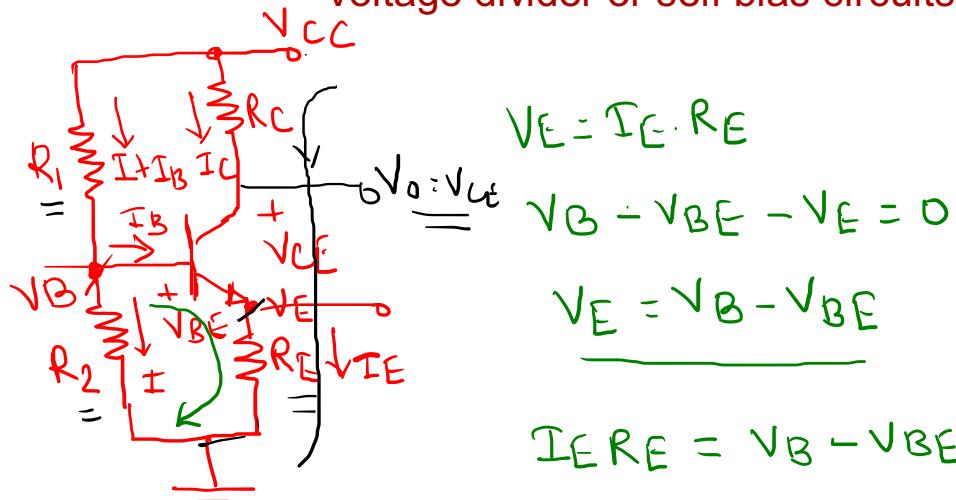
$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = V_{Th}$$

$$R_{Th} = R_1 \parallel (R_2 + R_E)$$



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

Voltage divider or self bias circuits



$$I_E R_E = V_B - V_{BE}$$

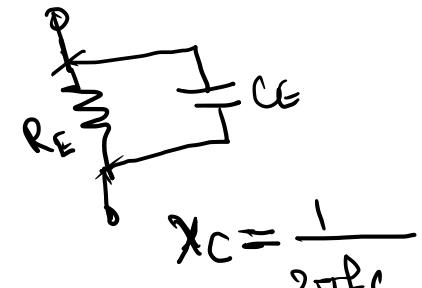
$$I_E = \frac{V_B - V_{BE}}{R_E} \quad \dots \textcircled{1}$$

At collector side : KVL

$$-I_C R_C - V_{CE} - I_E R_E + V_{CC} = 0$$

$$V_O = V_{CE} = V_{CC} - I_C R_C - I_E R_E \quad \dots \textcircled{2}$$

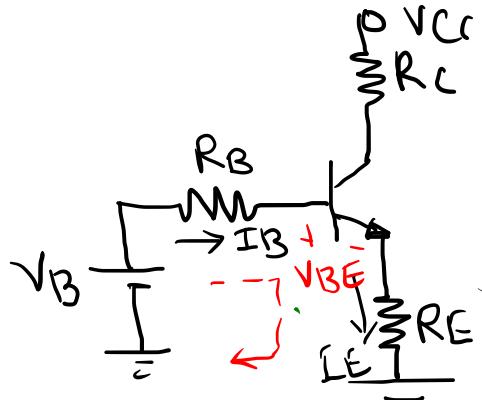
$I_E R_E \uparrow \quad V_O \downarrow \quad$ Negative Feedback



$$\text{DC } f = 0 \cdot X_C = \infty$$

$$\left. \begin{array}{l} R_E \\ \hline \end{array} \right| \left. \begin{array}{l} \text{AC } f = \infty \\ X_C = 0 \end{array} \right|$$

Stability factor for voltage divider Bias circuit



$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} \quad \& \quad R_B = R_1 / (R_2) = \frac{R_1 R_2}{R_1 + R_2}$$

$V_B - I_B R_B - V_{BE} - I_E R_E = 0 \quad \checkmark \quad \text{--- (1)}$

$I_E = I_B + I_C$

$$V_{BE} = V_B - (R_B + R_E) I_B - I_C R_E$$

$$S = \frac{\partial I_C}{\partial I_{CB0}} = \frac{1 + \beta}{1 + \beta \frac{\partial I_B}{\partial I_C}}$$

$$\frac{\partial I_B}{\partial I_C} = - \frac{R_E}{(R_B + R_E)} \quad \checkmark$$

$$S = \frac{1 + \beta}{1 + \beta \left(\frac{R_E}{R_B + R_E} \right)}$$

$$S = \frac{(1 + \beta)(R_B + R_E)}{R_B + R_E + \beta R_E}$$

$$S = \frac{(1 + \beta) \left(1 + \frac{R_B}{R_E} \right)}{(1 + \beta) + \frac{R_B}{R_E}}$$

$$\left\{ \begin{array}{l} \frac{R_B}{R_E} \ll 1 \Rightarrow 0 \\ R_E \uparrow \end{array} \right.$$

$$S = 1$$

$$\underline{R_B}, \underline{R_E}$$

$$\checkmark V_B = I_B R_B + V_{BE} + (I_B + I_E) R_E$$

diff w.r.t. I_C

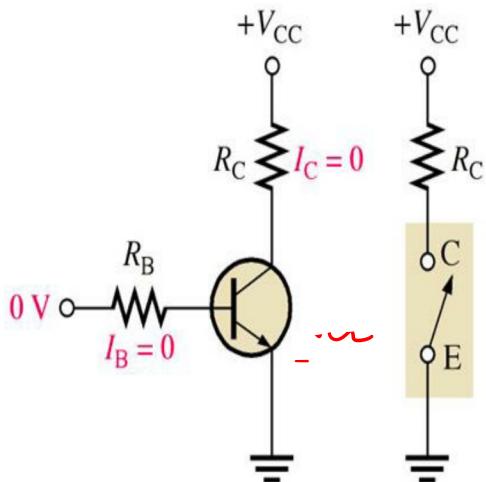
$$0 = \frac{\partial I_B}{\partial I_C} R_B + 0 + \frac{\partial I_B}{\partial I_C} R_E + R_E$$

Common Emitter Configuration applications

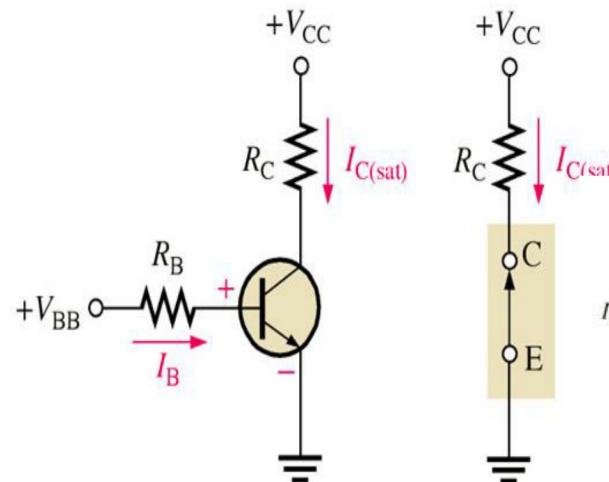
1. Transistor as (Electronic)Switch

A transistor when used as a switch is simply being biased so that it is in cut-off (switched off) or saturation (switched on). Remember that the VCE in cut-off is VCC and 0 V in saturation.

The dc load line graphically illustrates $I_C(\text{sat})$ and cut-off for a transistor.



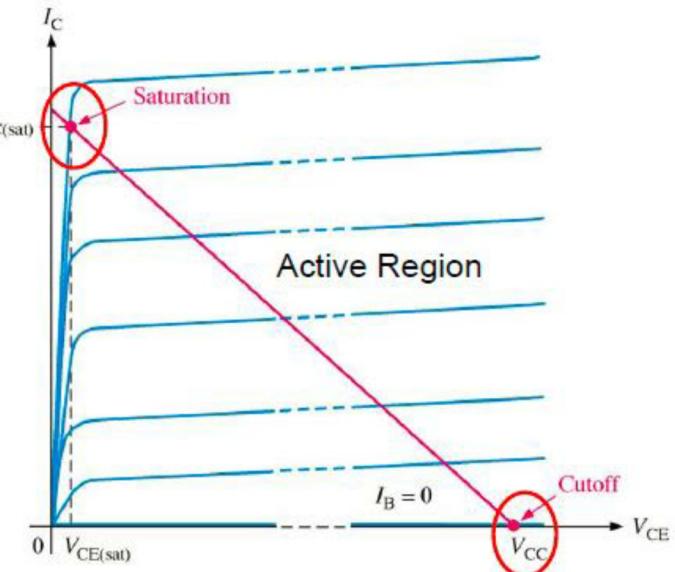
(a) Cutoff — open switch



(b) Saturation — closed switch

KVL(Collector-Emitter)

$$V_{CE} = V_{CC} - I_C R_C$$

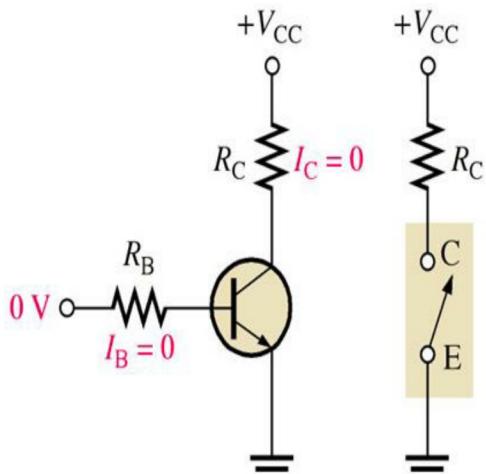


Common Emitter Configuration applications

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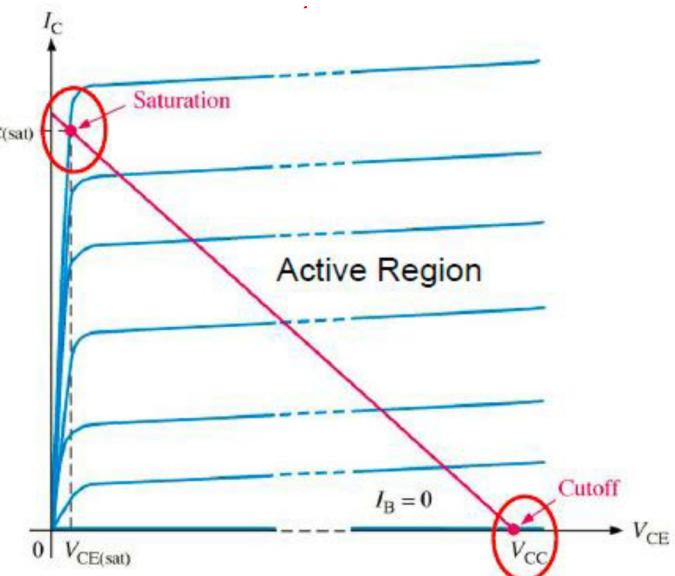


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KVL(Collector-Emitter)

$$V_{CE} = V_{CC} - I_C R_C$$



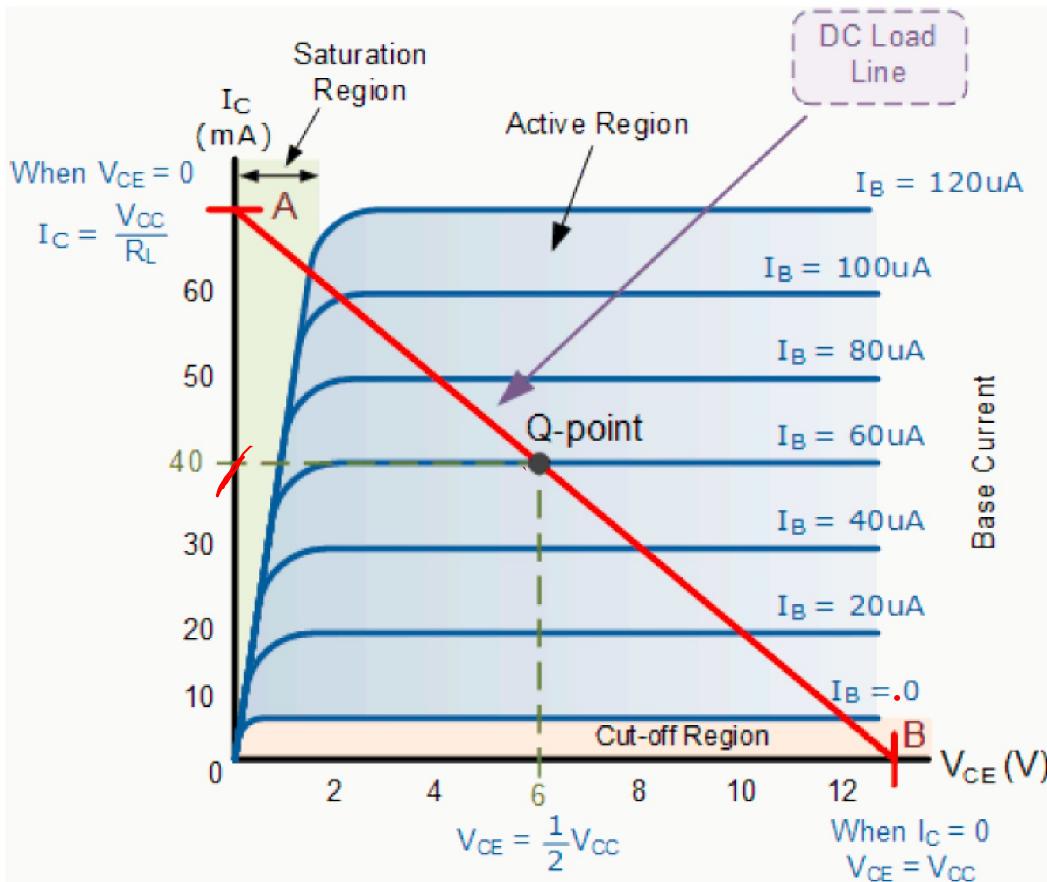
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

- BJT used as a semiconductor switch to turn load currents "ON" or "OFF" by controlling the Base signal to the transistor in either its saturation or cut-off regions.
- Transistors can also be used in its active region to produce a circuit which will amplify any small AC signal applied to its Base terminal with the Emitter grounded. If a suitable DC "biasing" voltage is firstly applied to the transistors Base terminal thus allowing it to always operate within its linear active region, an inverting amplifier circuit called a single stage common emitter amplifier is produced.
- One such Common Emitter Amplifier configuration of the transistor is called a Class A Amplifier. A "Class A Amplifier" operation is one where the transistors Base terminal is biased in such a way as to forward bias the Base-emitter junction. The result is that the transistor is always operating halfway between its cut-off and saturation regions, thereby allowing the transistor amplifier to accurately reproduce the positive and negative halves of any AC input signal superimposed upon this DC biasing voltage. Without this "Bias Voltage" only one half of the input waveform would be amplified.
- A DC "Load Line" can also be drawn onto the output characteristics curves to show all the possible operating points when different values of base current are applied. It is necessary to set the initial value of V_{ce} correctly to allow the output voltage to vary both up and down when amplifying AC input signals and this is called setting the operating point or Quiescent Point, **Q-point**

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



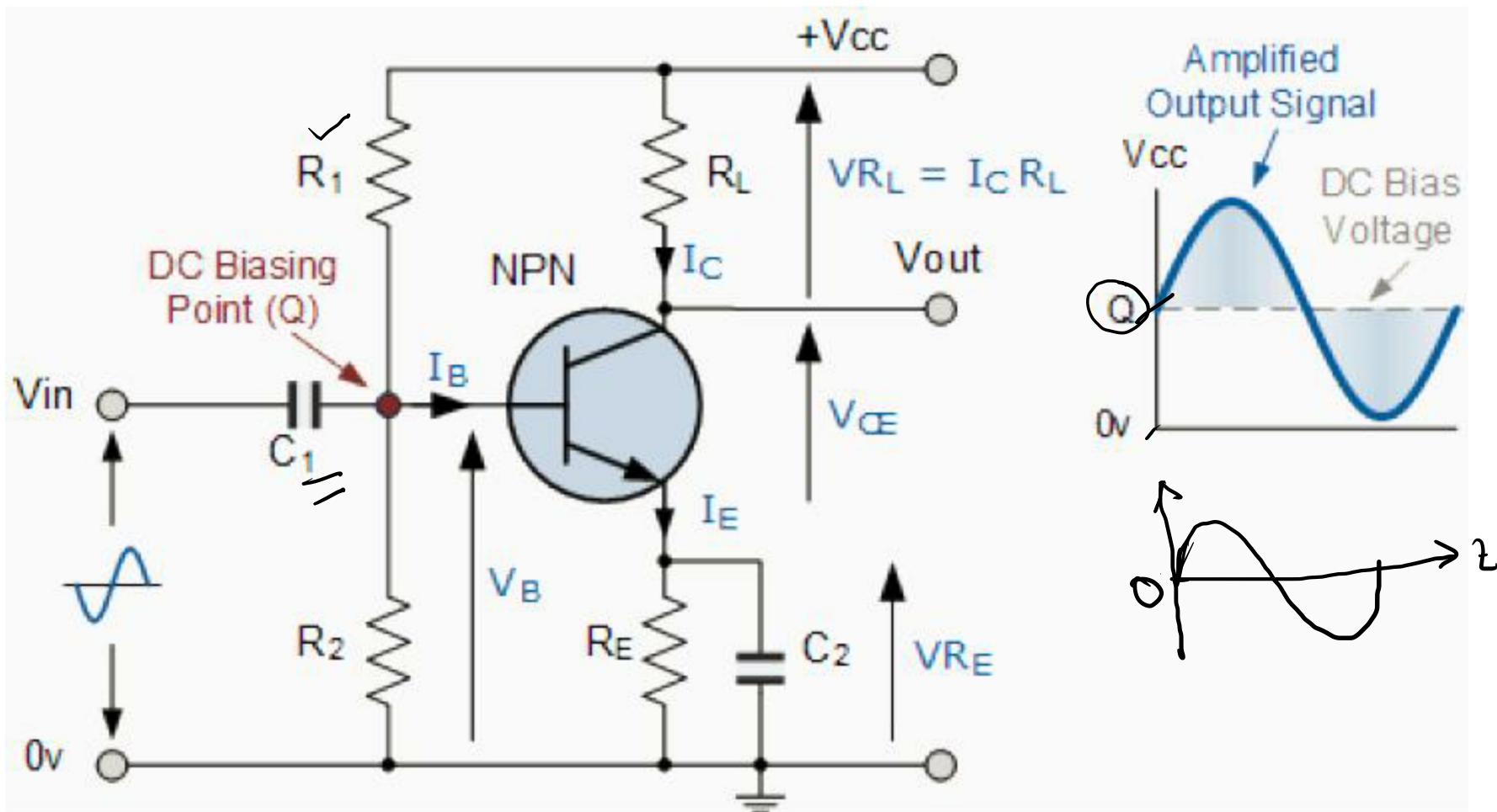
- Using the output characteristics curves and Ohm's Law, the current flowing through the load resistor, (R_L), is equal to the collector current, I_C entering the transistor which in turn corresponds to the supply voltage, (V_{CC}) minus the voltage drop between the collector and the emitter terminals, (V_{CE}) and is given as:

$$\text{Collector Current, } I_C = \frac{V_{CC} - V_{CE}}{R_L}$$

- A straight line representing the Load Line of the transistor can be drawn directly onto the graph of curves above from the point of "Saturation" (A) when $V_{CE} = 0$ to the point of "Cut-off" (B) when $I_C = 0$ thus giving us the "Operating" or Q-point of the transistor. These two points are joined together by a straight line and any position along this straight line represents the "Active Region" of the transistor.

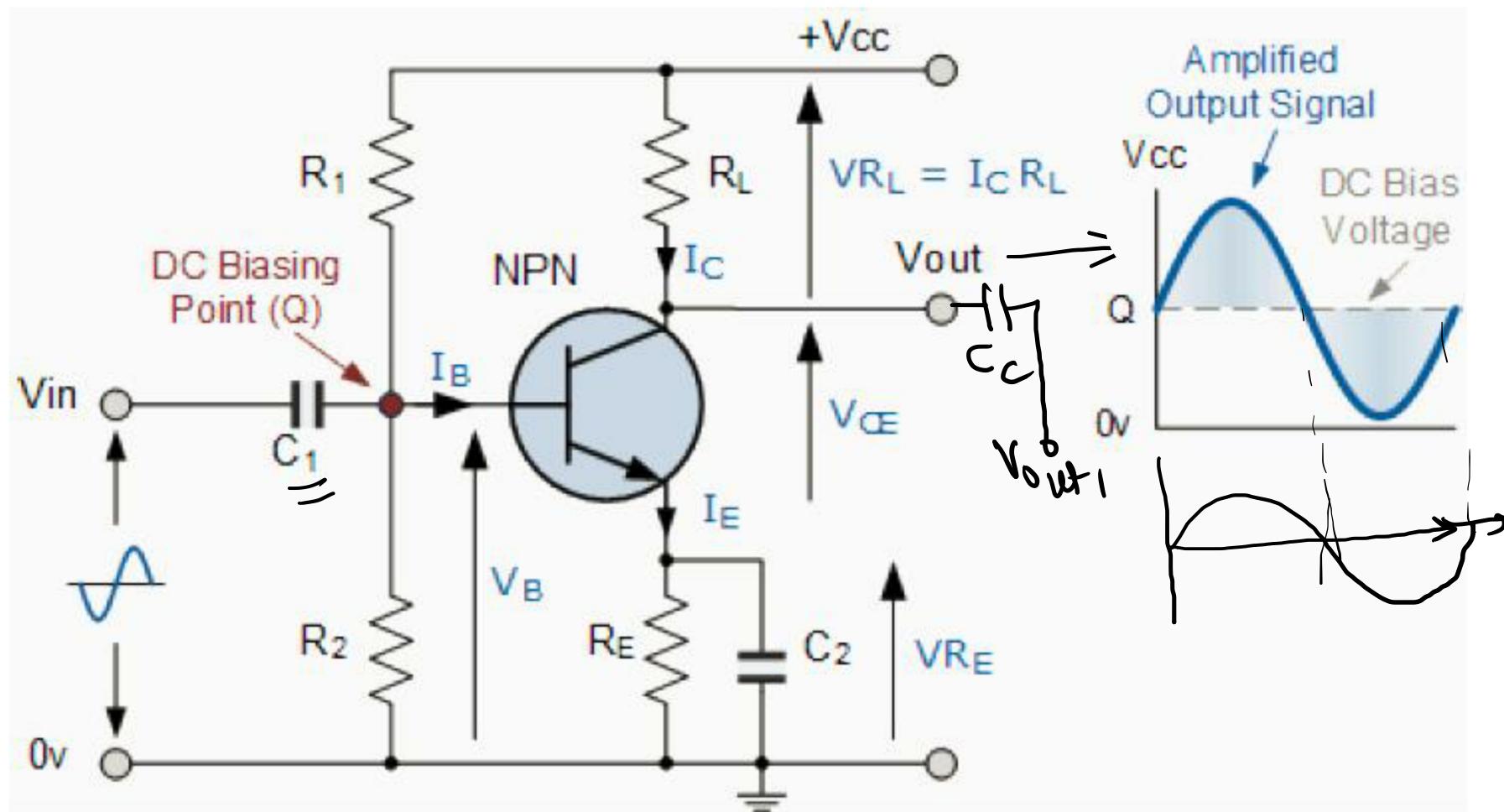
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



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Common Emitter Configuration applications

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The actual position of the load line on the characteristics curves can be calculated as follows

$$\text{When: } (V_{CE} = 0) \quad I_C = \frac{V_{CC} - 0}{R_L}, \quad I_C = \frac{V_{CC}}{R_L} \quad \equiv$$

$$\text{When: } (I_C = 0) \quad 0 = \frac{V_{CC} - V_{CE}}{R_L}, \quad V_{CC} = V_{CE} \quad \equiv$$

- Then, the collector or output characteristics curves for Common Emitter Transistors can be used to predict the Collector current, I_C , when given V_{CE} and the Base current, I_B . A Load Line can also be constructed onto the curves to determine a suitable Operating or Q-point which can be set by adjustment of the base current.

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

Design Steps: Approximate Formulae

1. Choose supply voltage V_{cc}
2. Choose collector current (I_C)
3. Choose transistor (h_{fe} or $\beta = ??$)
4. Find collector Resistor $R_C \approx (V_{cc}/I_C)/2$
5. Find emitter resistance $R_E \approx 0.1V_{cc}/(I_C/2)$
6. Choose emitter bypass capacitor $C_E = (1/2\pi f R_E)$
7. Find base current $I_B = I_C/\beta$
8. Base voltage $V_{BB} = \underbrace{V_E}_{=} (0.1V_{cc}) + \underbrace{V_{BE}}_{=} (0.7V)$
9. Find R_1 and R_2

$$V_{BB} = (V_{cc} \times R_2 / (R_1 + R_2))$$

choose R_1 / R_2 and find R_2/R_1 using above equation