ELECTRONIC DEVICES AND CIRCUITS

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Unit-1

TRANSISTOR CHARACTERISTICS

Introduction

- The basic of electronic system nowadays is semiconductor device.
- The famous and commonly use of this device is BJTs (Bipolar Junction Transistors).
- It can be use as amplifier and logic switches.
- BJT consists of three terminal:
  - collector : C
  - base : B
  - emitter : E
- Two types of BJT : pnp and npn

Transistor Construction

- 3 layer semiconductor device consisting:
  - 2 n- and 1 p-type layers of material · npn transistor
  - 2 p- and 1 n-type layers of material · pnp transistor
- The term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material
- A single pn junction has two different types of bias:
  - forward bias
  - reverse bias
- Thus, a two-pn-junction device has four types of bias.

Position of the terminals and symbol of BJT.

- Base is located at the middle and more thin from the level of collector and emitter
- The emitter and collector terminals are made of the same type of semiconductor material, while the base of the other type of material

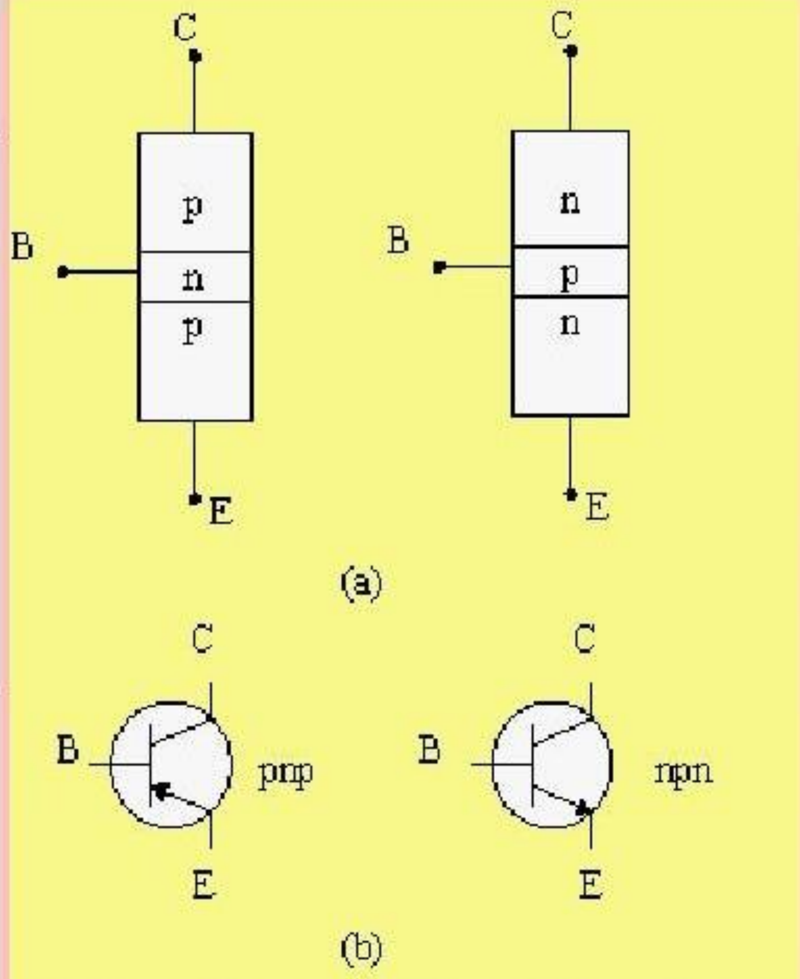
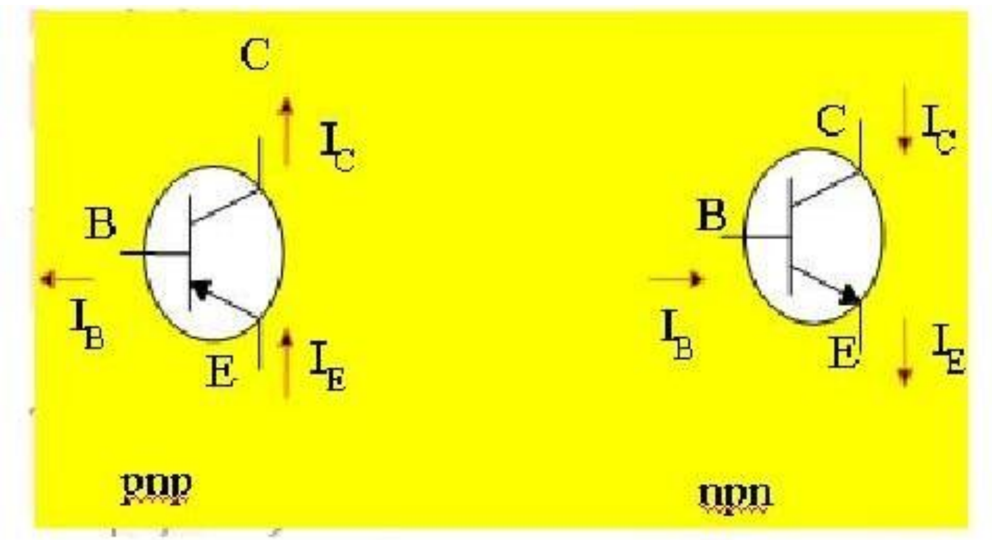


Fig. 4.1: (a) Position of terminals (b) Type of BJT

Transistor currents



I_C=the collector current
I_B= the base current
I_E= the emitter current

-The arrow is always drawn on the emitter

-The arrow always point toward the n-type

-The arrow indicates the direction of the emitter current:

pnp:E· B
npn: B· E

- By imaging the analogy of diode, transistor can be construct like two diodes that connetecd together.
- It can be conclude that the work of transistor is base on work of diode.

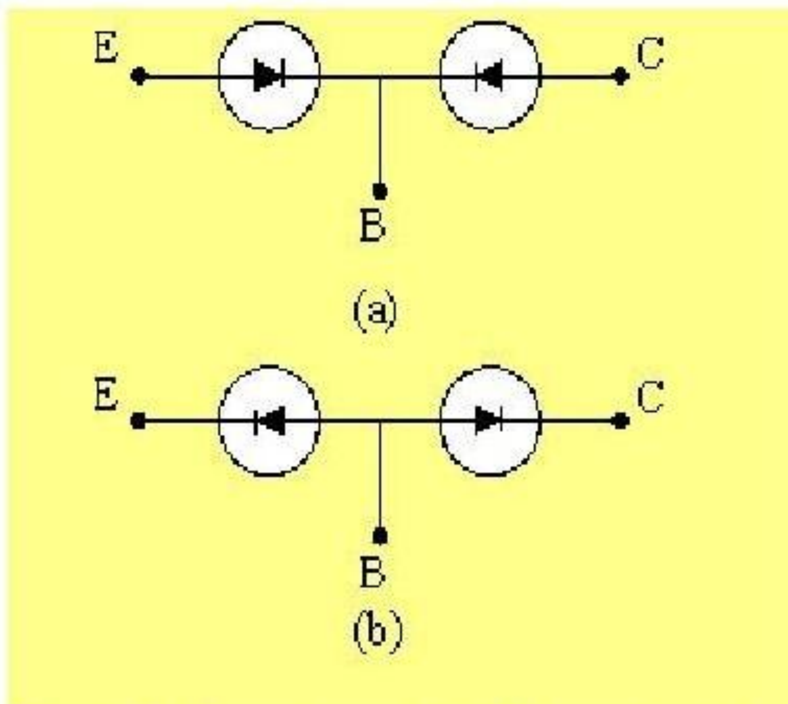
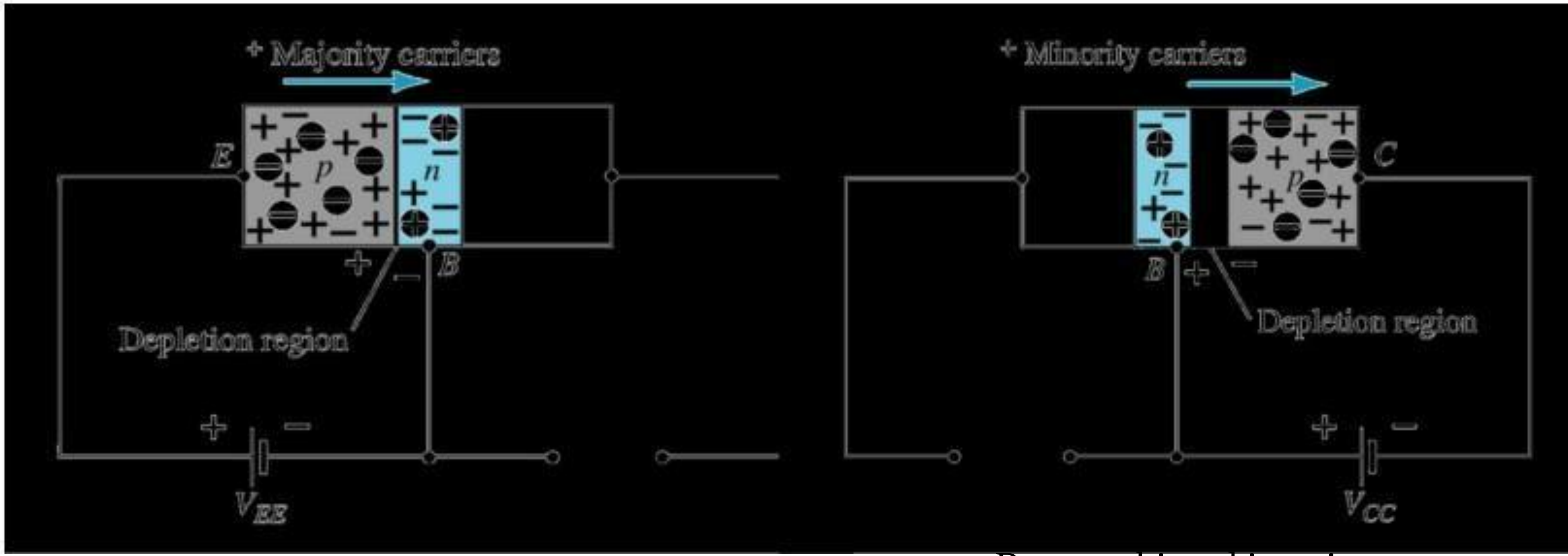


Fig. 4.2: (a) pnp transistor (b) npn transistor

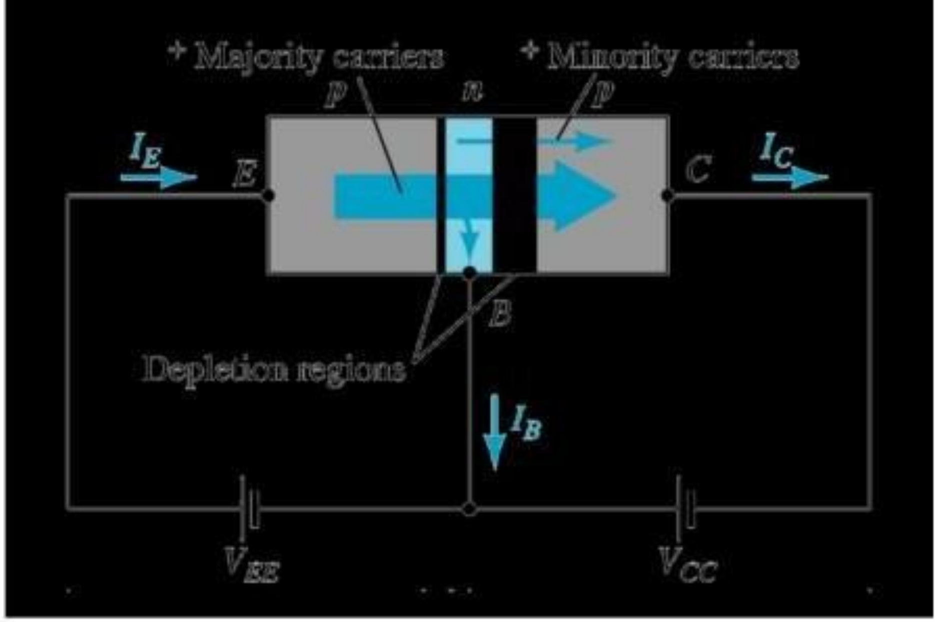
Transistor Operation

- The basic operation will be described using the pnp transistor. The operation of the pnp transistor is exactly the same if the roles played by the electron and hole are interchanged.
- One p-n junction of a transistor is reverse-biased, whereas the other is forward-biased.



Forward-biased junction of a pnp transistor

Reverse-biased junction of a pnp transistor



- Both biasing potentials have been applied to a pnp transistor and resulting majority and minority carrier flows indicated.
- Majority carriers (+) will diffuse across the forward-biased p-n junction into the n-type material.
- A very small number of carriers (+) will through n-type material to the base terminal. Resulting IB is typically in order of microamperes.
- The large number of majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal.

- Majority carriers can cross the reverse-biased junction because the injected majority carriers will appear as minority carriers in the n-type material.
- Applying KCL to the transistor :

$$I_E = I_C + I_B$$

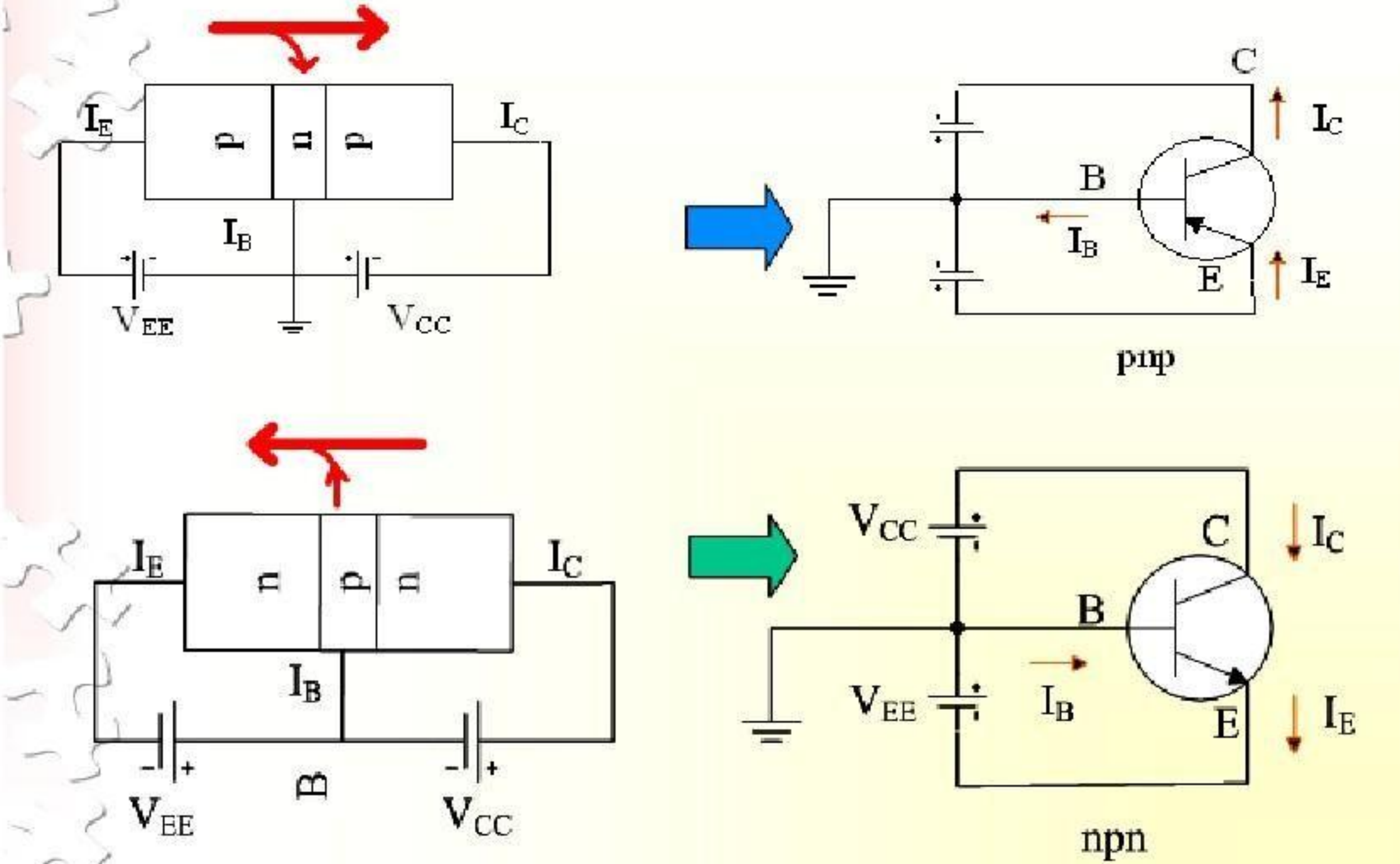
- The comprises of two components - the majority and minority carriers

$$I_C = I_{Cmajority} + I_{COminority}$$

- I_{CO} - I_C current with emitter terminal open and is called leakage current.

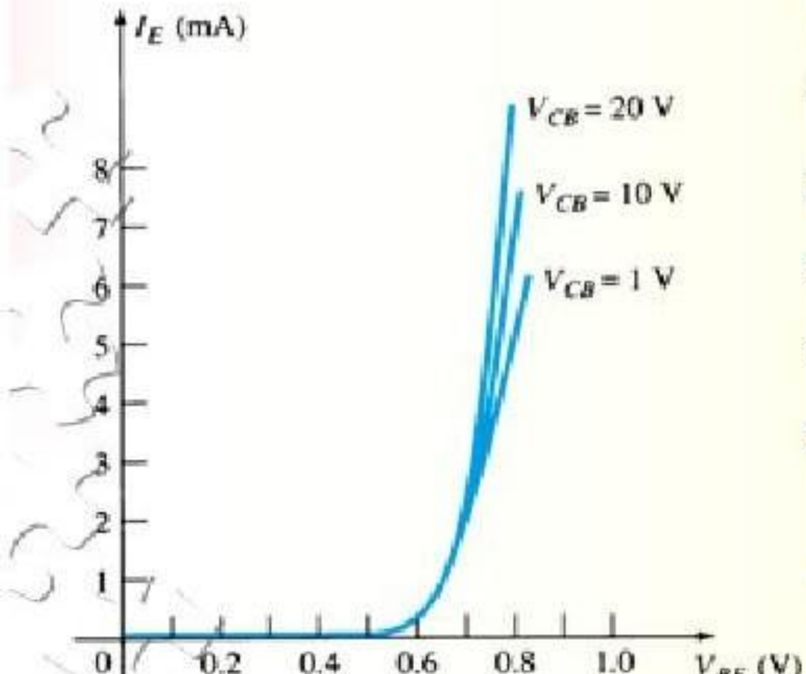
Common-Base Configuration

- Common-base terminology is derived from the fact that the :-
  base is common to both input and output of the configuration.
  - base is usually the terminal closest to or at ground potential.
- All current directions will refer to conventional (hole) flow and the arrows in all electronic symbols have a direction defined by this convention.
- Note that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.

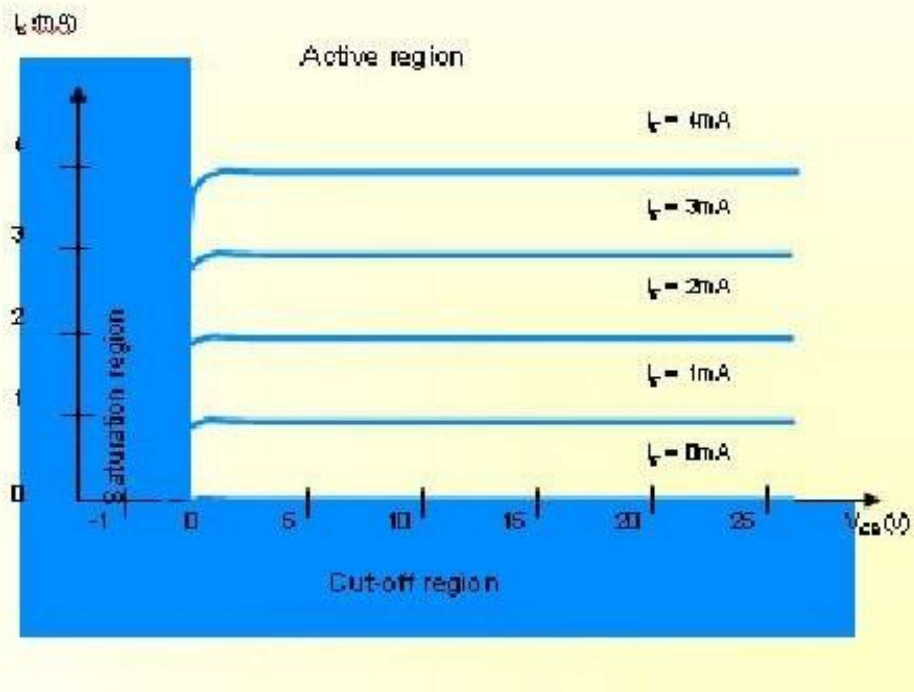


I_E
p
n
p
I_C
I_B
V_EE
V_CC
C
I_C
B
I_B
E
I_E
pnp
I_E
n
p
n
I_C
I_B
B
V_EE
V_CC
V_CC
C
I_C
B
V_EE
I_B
E
I_E
npn

- To describe the behavior of common-base amplifiers requires two set of characteristics:
  - Input or driving point characteristics.
  - Output or collector characteristics
- The output characteristics has 3 basic regions:
  - Active region -defined by the biasing arrangements
  - Cutoff region - region where the collector current is 0A
  - Saturation region- region of the characteristics to the left of V_{CB} = 0V



Input characteristics for a common silicon transistor



Output of collector characteristics for common-base transistor amplifier

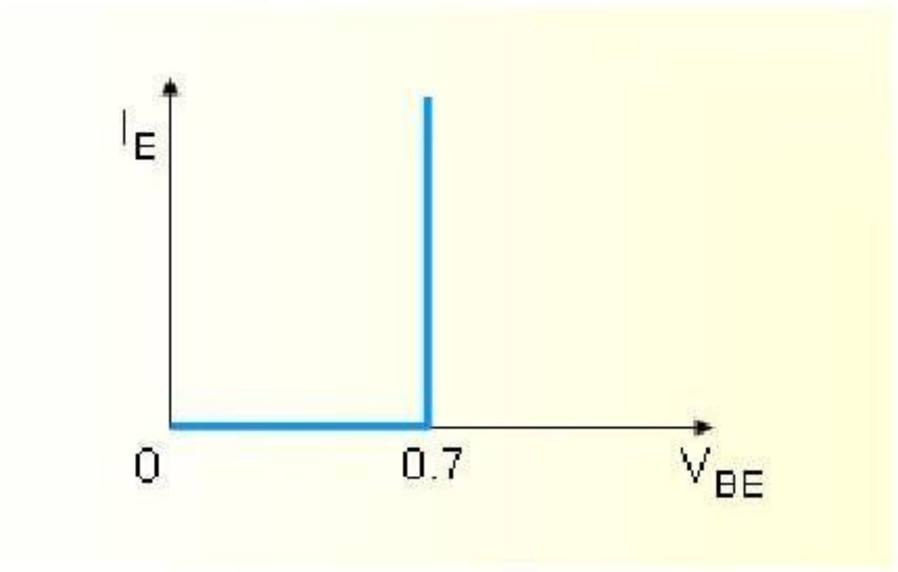
Active region	Saturation region	Cut-off region
• I_E increased, I_C increased • BE junction forward bias and CB junction reverse bias • Refer to the graf, $I_C \approx I_E$ • I_C not depends on V_{CB} • Suitable region for the transistor working as amplifier	• BE and CB junction is forward bias • Small changes in V_{CB} will cause big different to I_C • The allocation for this region is to the left of V_{CB}= 0 V.	• Region below the line of I_E=0 A • BE and CB is reverse bias • no current flow at collector, only leakage current

- The curves (output characteristics) clearly indicate that a first approximation to the relationship between IE and IC in the active region is given by

$$I_C \approx I_E$$

- Once a transistor is in the ‘on’ state, the base-emitter voltage will be assumed to be

$$V_{BE} = 0.7V$$



- In the dc mode the level of I_C and I_E due to the majority carriers are related by a quantity called alpha

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

$$I_C = aI_E + I_{CBO}$$

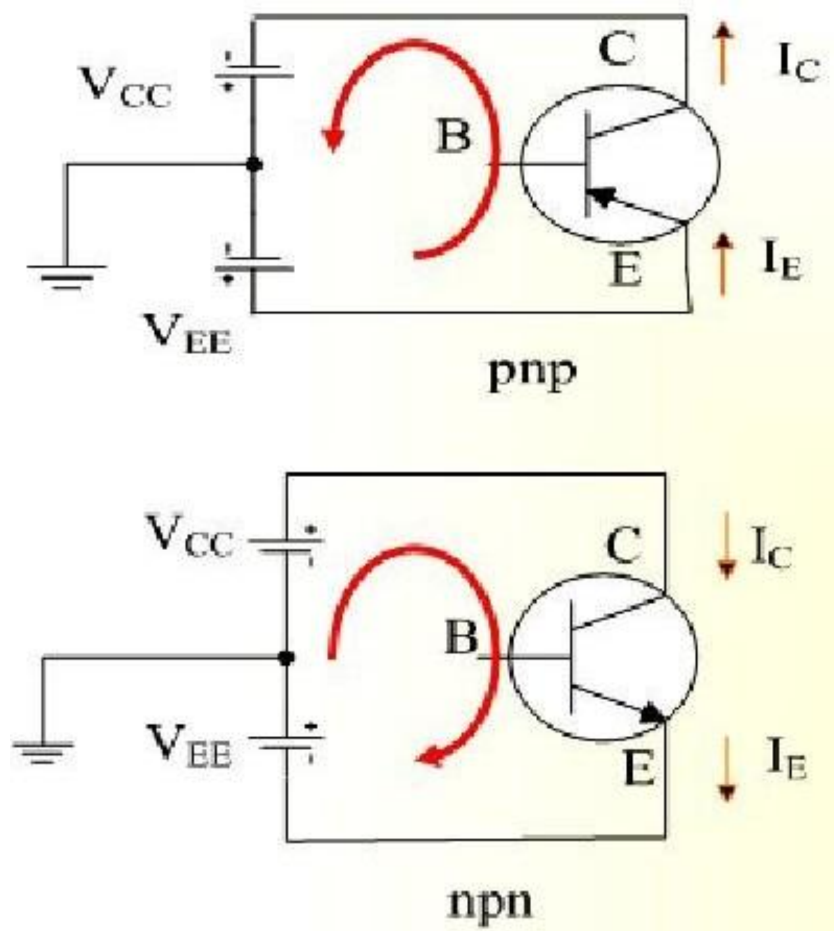
- It can then be summarize to $I_C = aI_E$ (ignore I_{CBO} due to small value)
- For ac situations where the point of operation moves on the characteristics curve, an ac alpha defined by

$$a \; . \; \frac{DI_C}{DI_E}$$

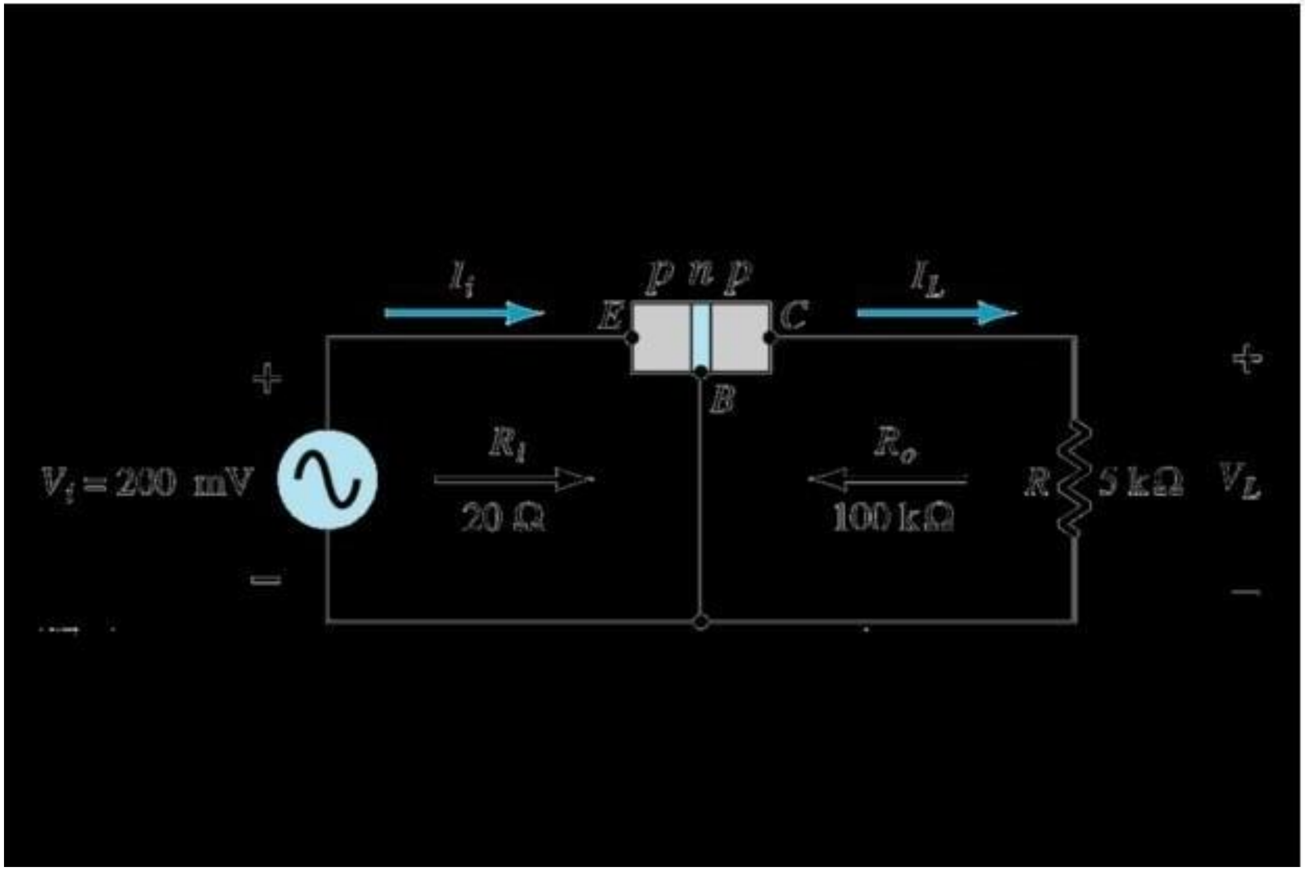
- Alpha a [redacted]t shows the efficiency by calculating the current percent from current flow from emitter to collector.The value of a is typical from 0.9 ~ 0.998.

Biasing

- Proper biasing CB configuration in active region by approximation I_C • I_E (I_B • 0 uA)



Transistor as an amplifier



Common-Emitter Configuration

- It is called common-emitter configuration since :

  - emitter is common or reference to both input and output terminals.

  -emitter is usually the terminal closest to or at ground potential.

- Almost amplifier design is using connection of CE due to the high gain for current and voltage

- Two set of characteristics are necessary to describe the behavior for CE ;input (base terminal) and output (collector terminal) parameters.

Proper Biasing common-emitter configuration in active region

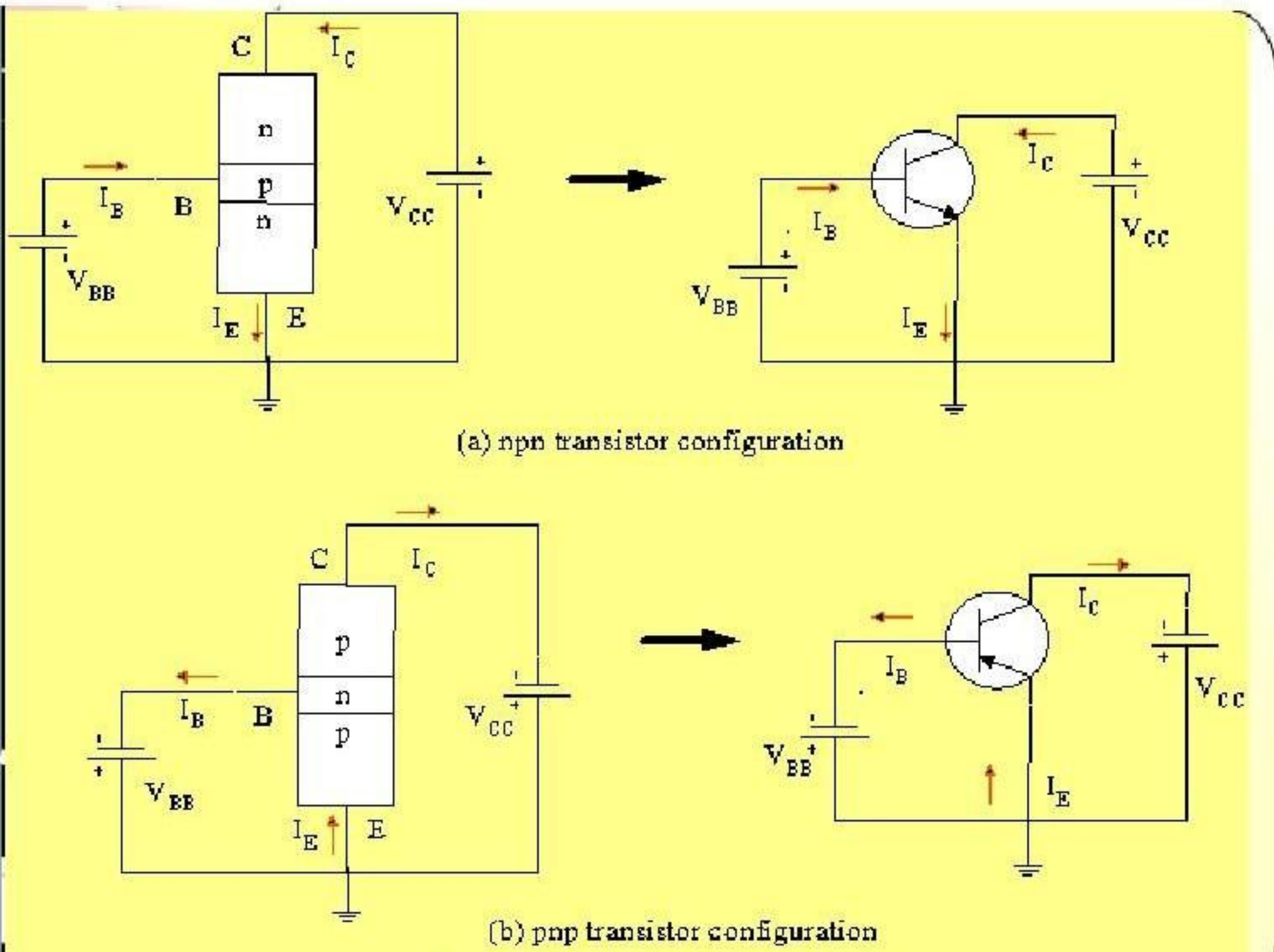
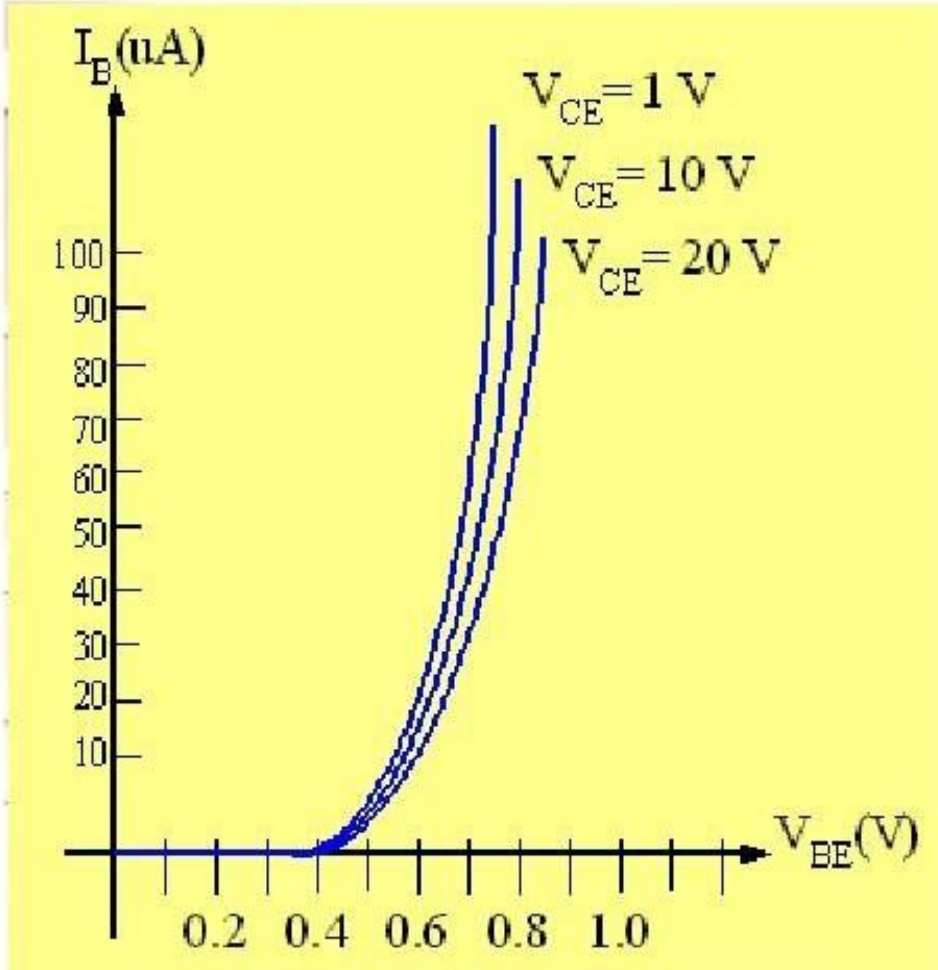


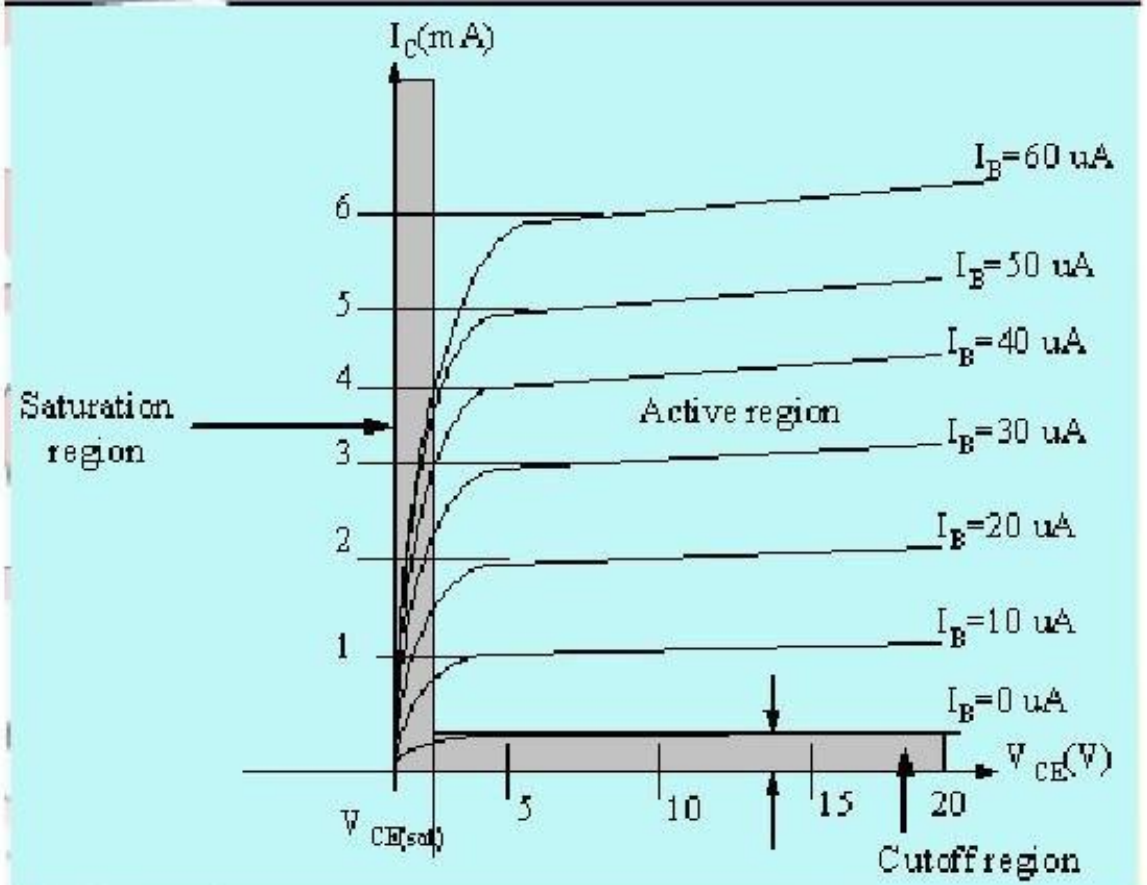
Fig 4.7 : Common-emitter configuration

$$\boxed{I_E = I_C + I_B}$$



Input characteristics for a common emitter NPN transistor

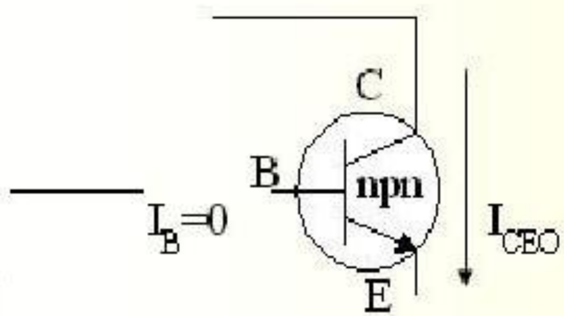
- I_B is microamperes compared to miliamperes of I_C.
- I_B will flow when V_{BE} > 0.7V for silicon and 0.3V for germanium
- Before this value I_B is very small and no I_B.
- Base-emitter junction is forward bias
- Increasing V_{CE} will reduce I_B for different values.

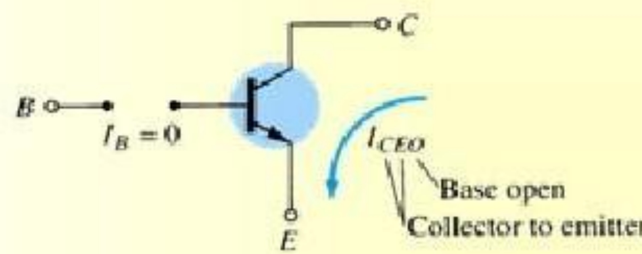


Output characteristics for a common-emitter npn transistor

- For small V_{CE} ($V_{CE} < V_{CESAT}$, I_C increase linearly with increasing of V_{CE}
- $V_{CE} > V_{CESAT}$ I_C not totally depends on V_{CE} ・ constant I_C
- I_B(uA) is very small compare to I_C (mA). Small increase in I_B cause big increase in I_C
- I_B=0 A ・ I_{CEO} occur.
- Noticing the value when I_C=0A. There is still some value of current flows.

Active region	Saturation region	Cut-off region
• B-E junction is forward bias • C-B junction is reverse bias • can be employed for voltage, current and power amplification	• B-E and C-B junction is forward bias, thus the values of I_B and I_C is too big. • The value of V_{CE} is so small. • Suitable region when the transistor as a logic switch. • NOT and avoid this region when the transistor as an amplifier.	• region below $I_B=0\mu A$ is to be avoided if an undistorted o/p signal is required • B-E junction and C-B junction is reverse bias • $I_B=0$, I_C not zero, during this condition $I_C=I_{CEO}$ where is this current flow when B-E is reverse bias.

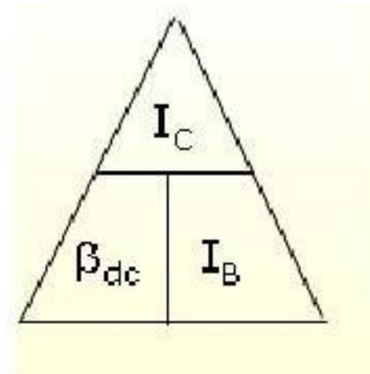




Beta (E) or amplification factor

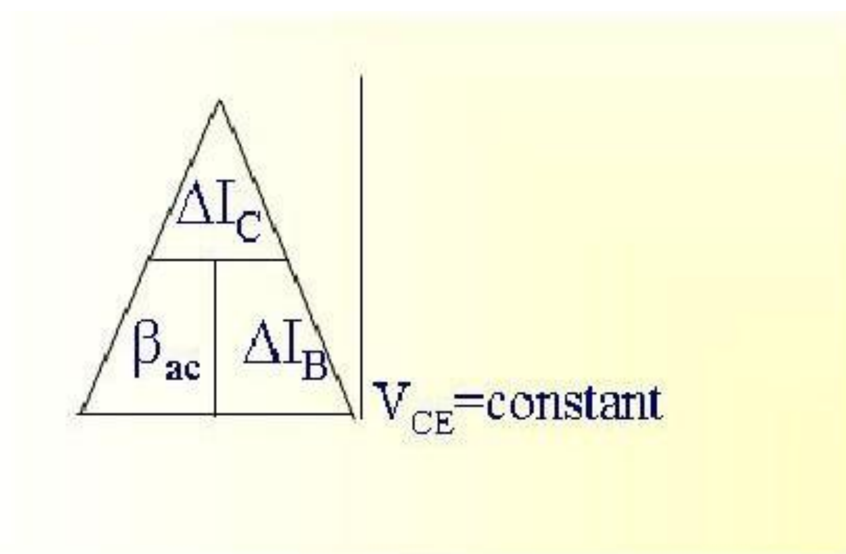
- The ratio of dc collector current (IC) to the dc base current (IB) is dc beta (Edc) which is dc current gain where IC and IB are determined at a particular operating point, Q-point (quiescent point).
- It’s define by the following equation:

30 < Edc < 300 · 2N3904



- On data sheet, E[redacted]n *h*[redacted]erived from ac hybrid equivalent cct. FE are derived from forward-current amplification and common-emitter configuration respectively.

- For ac conditions an ac beta has been defined as the changes of collector current (I_C) compared to the changes of base current (I_B) where I_C and I_B are determined at operating point.
- On data sheet, E_{ac}=*hfe*
- It can defined by the following equation:



Example

From output characteristics of common emitter configuration, find E_{ac} and E_{dc} with an Operating point at I_B=25・ A and V_{CE} =7.5V.

Solution:

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE} = \text{constant}}$$

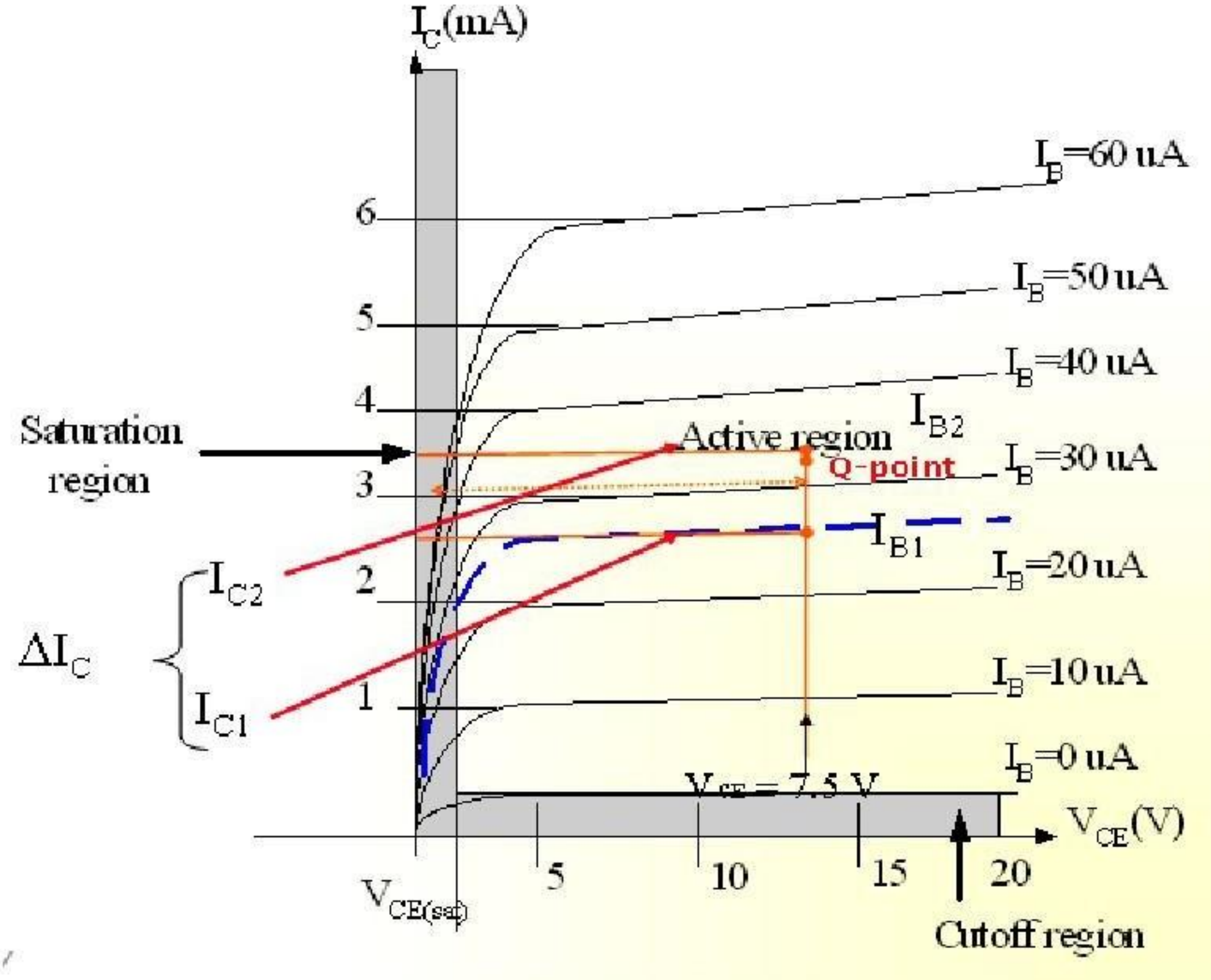
$$= \frac{I_{C2} - I_{C1}}{I_{B2} - I_{B1}} = \frac{3.2m - 2.2m}{30\mu - 20\mu}$$

$$= \frac{1m}{10\mu} = 100$$

$$\beta_{dc} = \frac{I_C}{I_B}$$

$$= \frac{2.7m}{25\mu}$$

$$= \underline{\underline{108}}$$



I_C(mA)
I_B=60 uA
I_B=50 uA
I_B=40 uA
I_{B2}
Active region
Q-point
I_B=30 uA
I_{B1}
I_B=20 uA
I_B=10 uA
I_B=0 uA
Saturation region
ΔI_C
I_{C2}
I_{C1}
6
5
4
3
2
1
V_{CE} = 7.5 V
V_{CE}(V)
5
10
15
20
$V_{CE(sat)}$
Cutoff region

Relationship analysis between α and β

CASE 1

$$I_E = I_C + I_B \qquad (1)$$

subtitute equ. $I_C = \beta I_B$ into (1) we get

$$\underline{\underline{I_E = (\beta + 1) I_B}}$$

CASE 2

known : $\alpha = \dfrac{I_C}{I_E} \Rightarrow I_E = \dfrac{I_C}{\alpha} \qquad (2)$

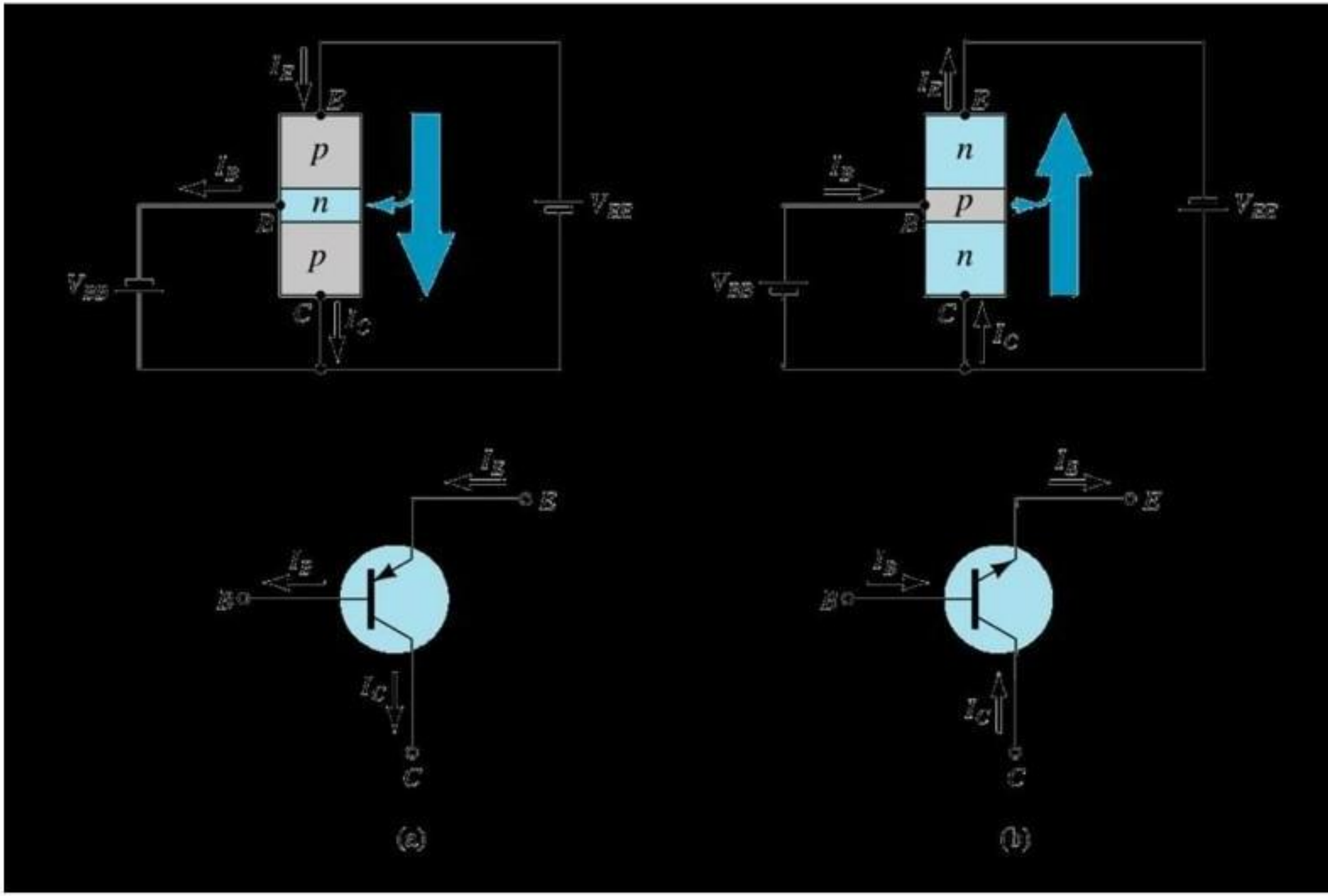
known : $\beta = \dfrac{I_C}{I_B} \Rightarrow I_B = \dfrac{I_C}{\beta} \qquad (3)$

subtitute (2) and (3) into (1) we get,

$$\underline{\underline{\alpha = \frac{\beta}{\beta + 1}}} \qquad \text{and} \qquad \underline{\underline{\beta = \frac{\alpha}{1 - \alpha}}}$$

Common - Collector Configuration

- Also called emitter-follower (EF).
- It is called common-emitter configuration since both the signal source and the load share the collector terminal as a common connection point.
- The output voltage is obtained at emitter terminal.
- The input characteristic of common-collector configuration is similar with common-emitter. configuration.
- Common-collector circuit configuration is provided with the load resistor connected from emitter to ground.
- It is used primarily for impedance-matching purpose since it has high input impedance and low output impedance.



Notation and symbols used with the common-collector configuration:
(a) pnp transistor ; (b) npn transistor.

- For the common-collector configuration, the output characteristics are a plot of I_E vs V_{CE} for a range of values of I_B.

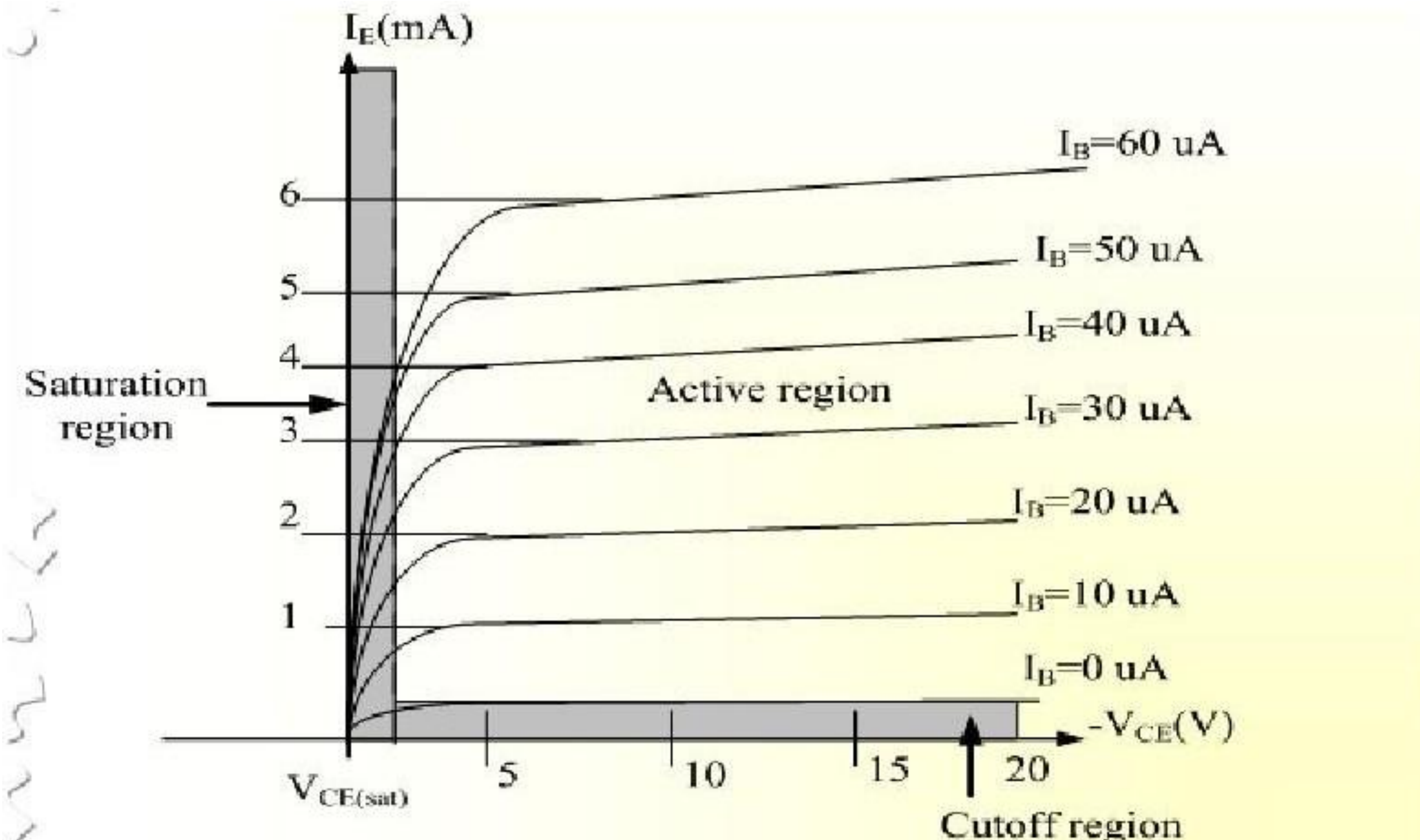


Fig 4.9 : Output characteristic in CC configuration for npn transistor

Limits of Operation

- Many BJT transistor used as an amplifier. Thus it is important to notice the limits of operations.
- At least 3 maximum values is mentioned in data sheet.
- There are:

  a) Maximum power dissipation at collector: P_{Cmax} or P_D

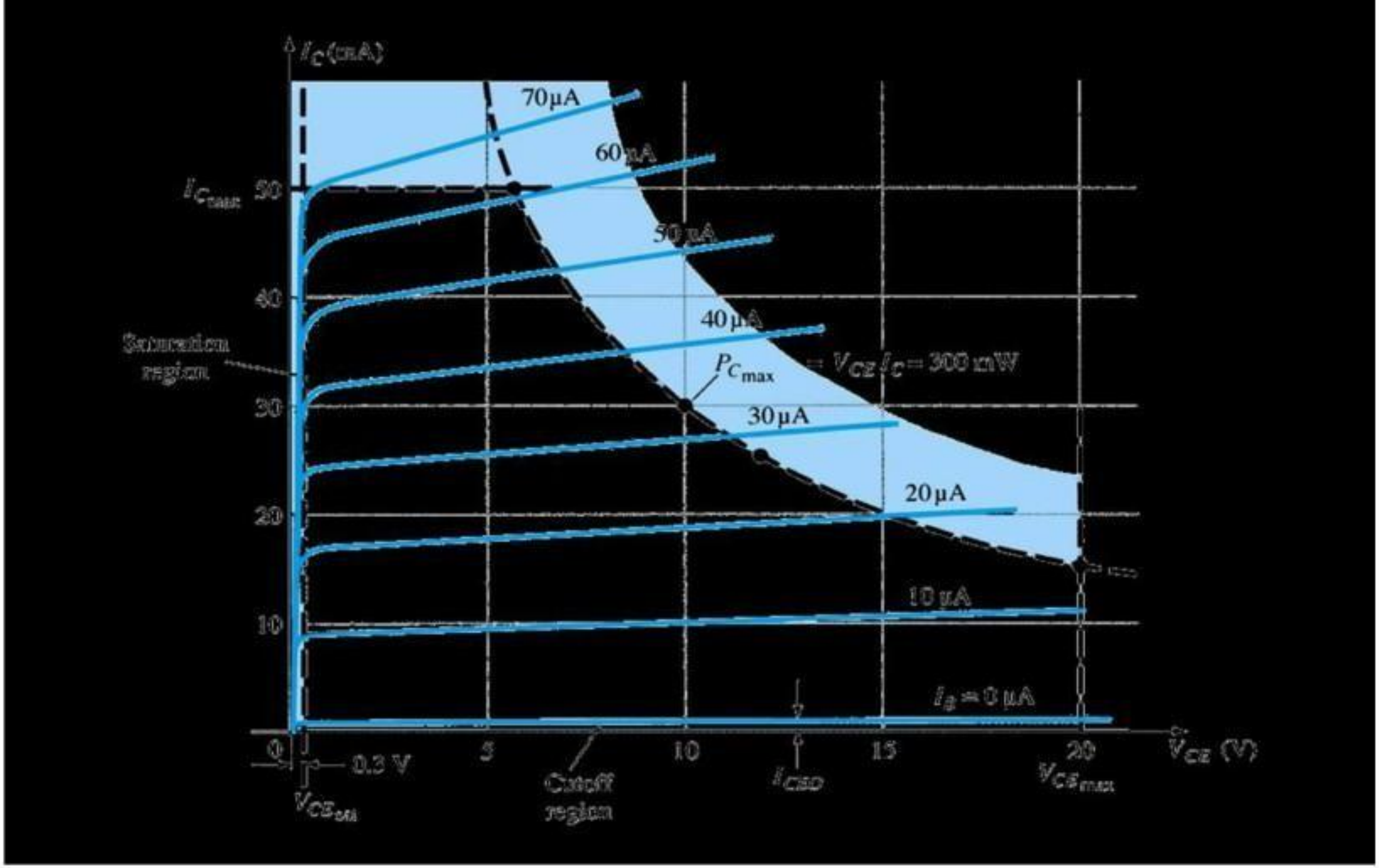
  b) Maximum collector-emitter voltage: V_{CEmax} sometimes named as $V_{BR(CEO)}$ or V_{CEO}.

  c) Maximum collector current: ICmax
- There are few rules that need to be followed for BJT transistor used as an amplifier. The rules are:

  i) transistor need to be operate in active region!

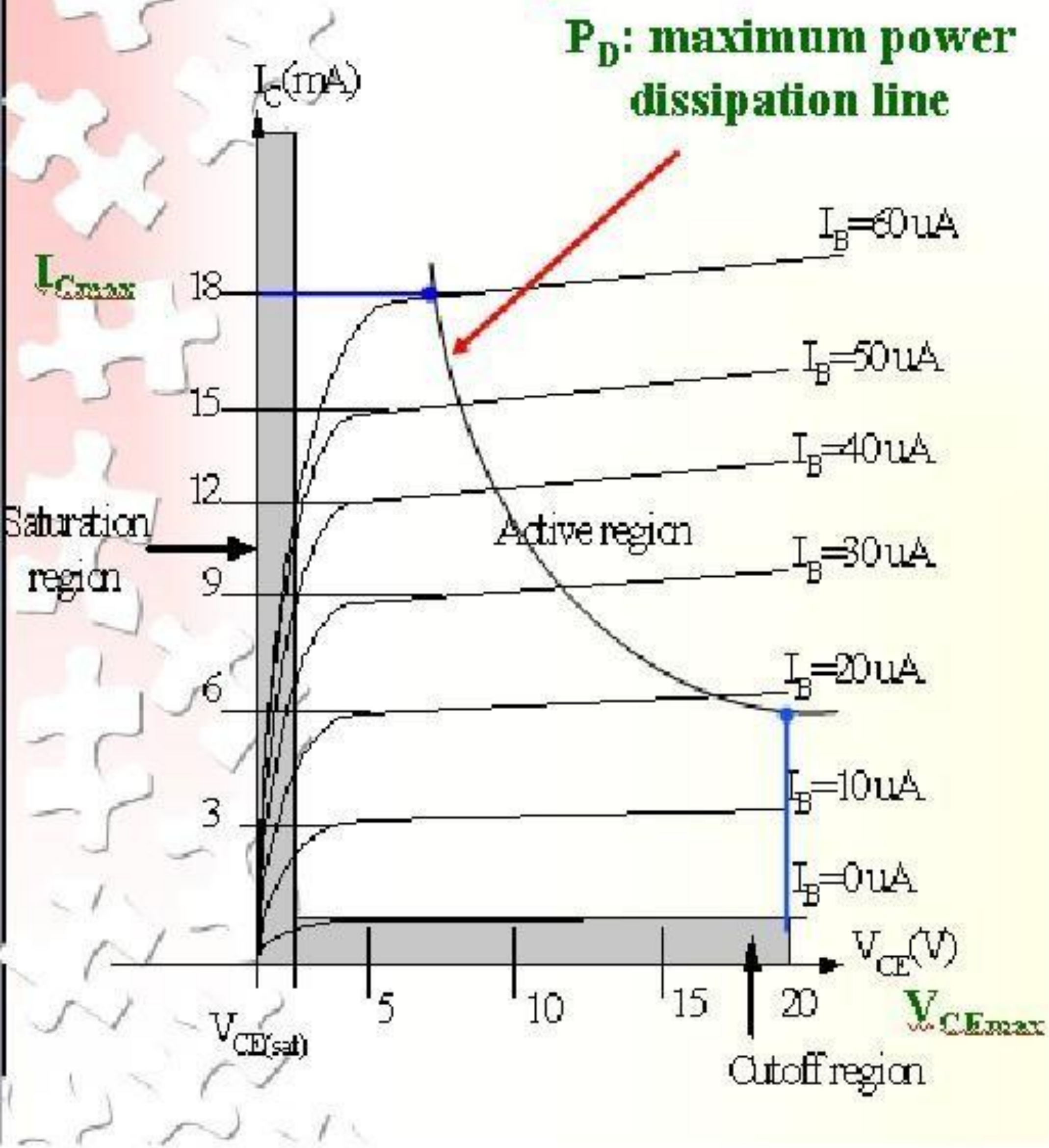
  ii) $I_C < I_{Cmax}$

  ii) $P_C < P_{Cmax}$



Note: V_{CE} is at maximum and I_C is at minimum ($I_{CMAX}=I_{CEO}$) in the cutoff region. I_C is at maximum and V_{CE} is at minimum (V_{CE} max = V_{cesat} = V_{CEO}) in the saturation region. The transistor operates in the active region between saturation and cutoff.

Example 1:



Refer to the fig.

Step1:

The maximum collector power dissipation,

$P_D = I_{CMAX} \times V_{CEmax}$ (1)

$= 18m \times 20 = 360$ mW

Step 2:

At any point on the characteristics the product of and must be equal to 360 mW.

Ex. 1. If choose I_{Cmax}= 5 mA, substitute into the (1), we get

$V_{CEmax}I_{Cmax}$= 360 mW

V_{CEmax}(5 m)=360/5=7.2 V

Ex.2. If choose V_{CEmax}=18 V, substitute into (1), we get

$V_{CEmax}I_{Cmax}$= 360 mW

(10) I_{CMAX}=360m/18=20 mA

Derating P_{Dmax}

- P_{DMAX} is usually specified at 25°C.
- The higher temperature goes, the less is P_{DMAX}
- Example;
  - A derating factor of 2mW/°C indicates the power dissipation is reduced 2mW each degree centigrade increase of temperature.

Transistor Biasing and Stabilization

Transistor Biasing

The basic function of transistor is amplification. The process of raising the strength of weak signal without any change in its general shape is referred as faithful amplification. For faithful amplification it is essential that:-

1. Emitter-Base junction is forward biased
2. Collector- Base junction is reversed biased
3. Proper zero signal collector current

The proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of signal is called transistor biasing.

WHY BIASING?

If the transistor is not biased properly, it would work inefficiently and produce distortion in output signal.

HOW A TRANSISTOR CAN BE BIASED?

A transistor is biased either with the help of battery or associating a circuit with the transistor. The later method is more efficient and is frequently used. The circuit used for transistor biasing is called the biasing circuit.

BIAS STABILITY

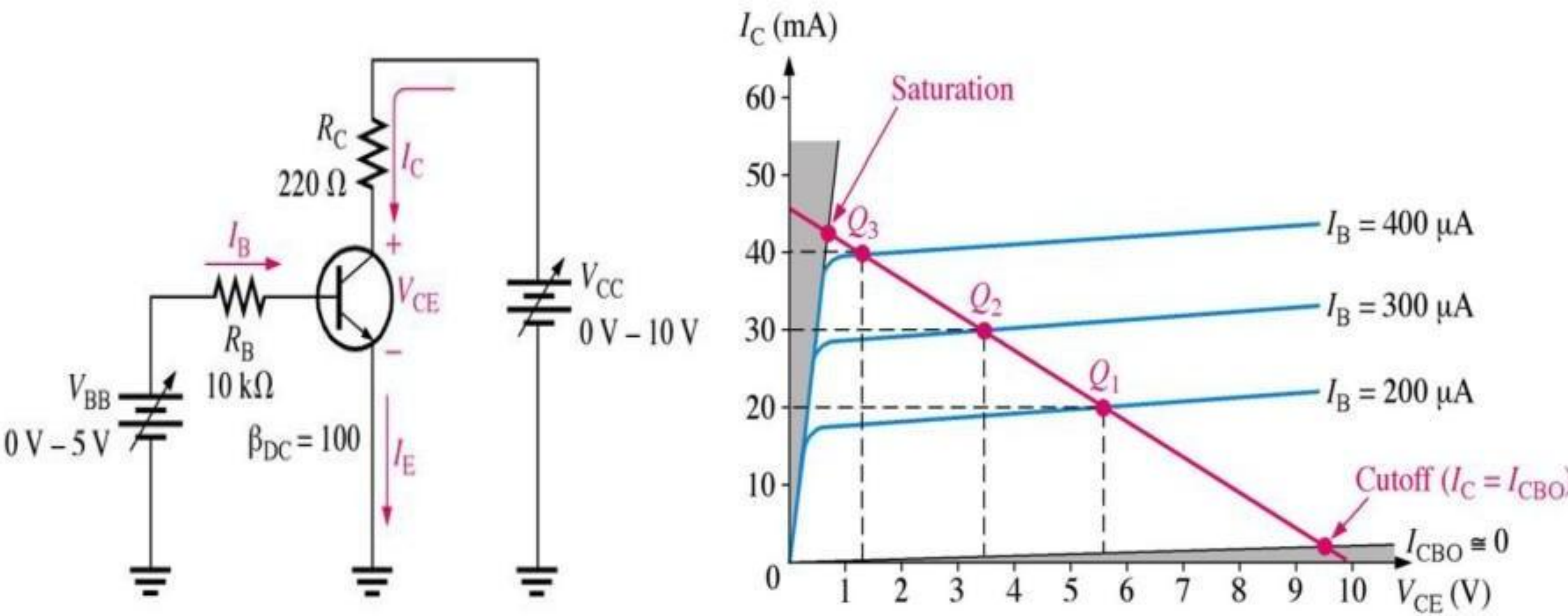
- Through proper biasing, a desired quiescent operating point of the transistor amplifier in the active region (linear region) of the characteristics is obtained. It is desired that once selected the operating point should remain stable. The maintenance of operating point stable is called Stabilisation.

- The selection of a proper quiescent point generally depends on the following factors:
  (a) The amplitude of the signal to be handled by the amplifier and distortion level in signal
  (b) The load to which the amplifier is to work for a corresponding supply voltage

- The operating point of a transistor amplifier shifts mainly with changes in temperature, since the transistor parameters— β, I_{CO} *and* V_{BE} *(where the symbols carry their usual meaning)—are functions of* temperature.

The DC Operating Point

For a transistor circuit to amplify it must be properly biased with dc voltages. The dc operating point between saturation and cutoff is called the **Q-point.** The goal is to set the Q-point such that that it does not go into saturation or cutoff when an a ac signal is applied.



(a) DC biased circuit

Requirements of biasing network

- Ensuring proper zero signal collector current.
- Ensuring V_{CE} not falling below 0.5V for Ge transistor and 1V for Silicon transistor at any instant.
- Ensuring Stabilization of operating point. (zero signal I_C and V_{CE})

The Thermal Stability of Operating Point (S_{Ico})

- **Stability Factor *S:-*** The stability factor *S, as the change of collector current with respect to the reverse saturation* current, keeping β *and VBE constant. This can be written as:*

The Thermal Stability Factor : S

S =

This equation signifies that Changes S times as fast as

Differentiatin th equatio Collecto Curre co
rearrangin th term w ca writ

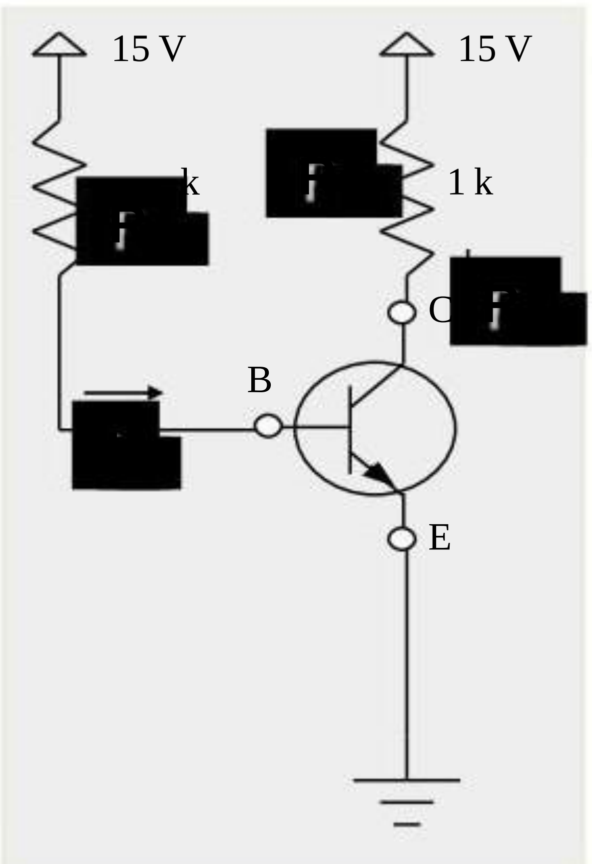
S = 1

It may be noted that Lower is the value of S better is the stabilit

Various Biasing Circuits

- **Fixed Bias Circuit**
- **Fixed Bias with Emitter Resistor**
- **Collector to Base Bias Circuit**
- **Potential Divider Bias Circuit**

The Fixed Bias Circuit



The Thermal Stability Factor : S_{I}

S_{I} = [redacted]

General Equation c S_{I} Comes out to be

S_{I} = 1 · [redacted]

Applying KVL through Base Circuit we can write, R + V = V

Diff w. r. t. , we get / ∂) =

S_{I} = (1) is very larg

Indicating high u stabili

Merits:

- It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).
- A very small number of components are required.

Demerits:

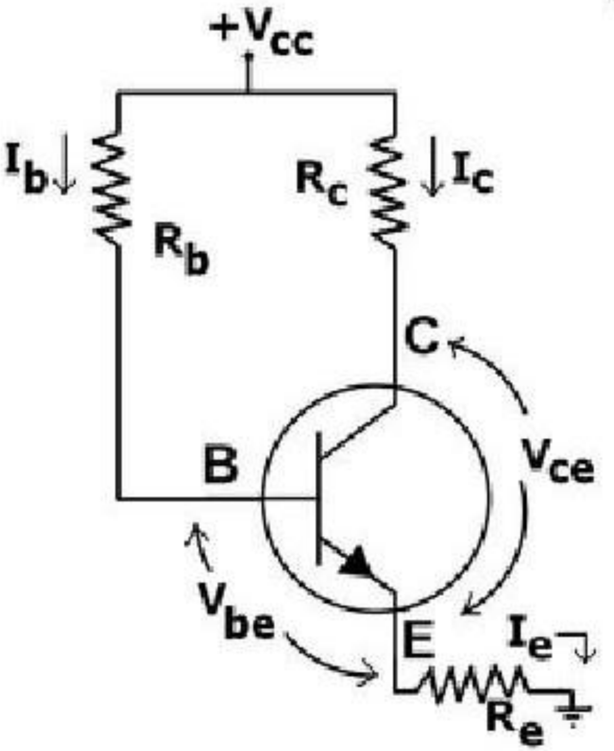
- The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.
- When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.
- For small-signal transistors (e.g., not power transistors) with relatively high values of β (i.e., between 100 and 200), this configuration will be prone to thermal runaway. In particular, the stability factor, which is a measure of the change in collector current with changes in reverse saturation current, is approximately β+1. To ensure absolute stability of the amplifier, a stability factor of less than 25 is preferred, and so small-signal transistors have large stability factors.

Usage:

- Due to the above inherent drawbacks, fixed bias is rarely used in linear circuits (i.e., those circuits which use the transistor as a current source). Instead, it is often used in circuits where transistor is used as a switch. However, one application of fixed bias is to achieve crude automatic gain control in the transistor by feeding the base resistor from a DC signal derived from the AC output of a later stage.

Fixed bias with emitter resistor

The fixed bias circuit is modified by attaching an external resistor to the emitter. This resistor introduces negative feedback that stabilizes the Q-point.



Merits:

- The circuit has the tendency to stabilize operating point against changes in temperature and β-value.

Demerits:

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E very large, or making R_B very low.

· If R_E is of large value, high V_{CC} is necessary. This increases cost as well as precautions necessary while handling.

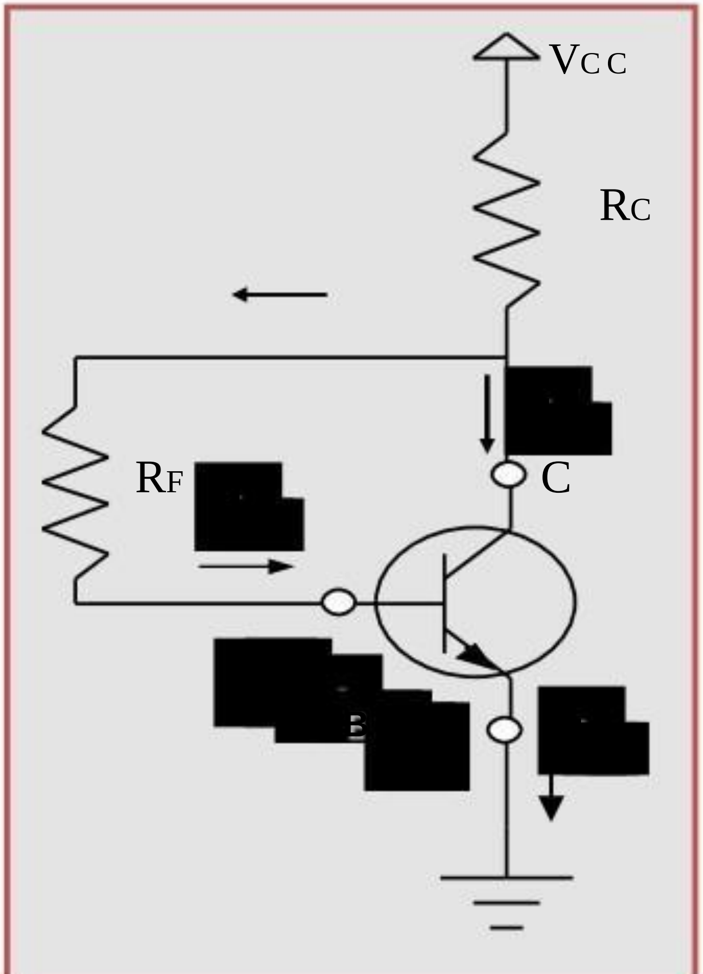
· If R_B is low, a separate low voltage supply should be used in the base circuit. Using two supplies of different voltages is impractical.

- In addition to the above, R_E causes ac feedback which reduces the voltage gain of the amplifier.

Usage:

The feedback also increases the input impedance of the amplifier when seen from the base, which can be advantageous. Due to the above disadvantages, this type of biasing circuit is used only with careful consideration of the trade-offs involved.

The Collector to Base Bias Circuit



This configuration employs negative feedback to prevent thermal runaway and stabilize the operating point. In this form of biasing, the base resistor R_F is connected to the collector instead of connecting it to the DC source V_{CC}. So any thermal runaway will induce a voltage drop across the R_C resistor that will throttle the transistor's base current.

Applying KVL through base circui

we can write (+) R + I + V = V

Diff. w. r. t. we ge

/ ∂) = R (R + R

Therefore S = (1+

1 R (R + R

Which is less than (1), signifying better thermal stabilit

Merits:

- Circuit stabilizes the operating point against variations in temperature and β (i.e. replacement of transistor)

Demerits:

•As β -value is fixed (and generally unknown) for a given transistor, this relation can be satisfied either by keeping R_C fairly large or making R_f very low.

- If R_C is large, a high V_{CC} is necessary, which increases cost as well as precautions necessary while handling.
- If R_f is low, the reverse bias of the collector-base region is small, which limits the range of collector voltage swing that leaves the transistor in active mode.

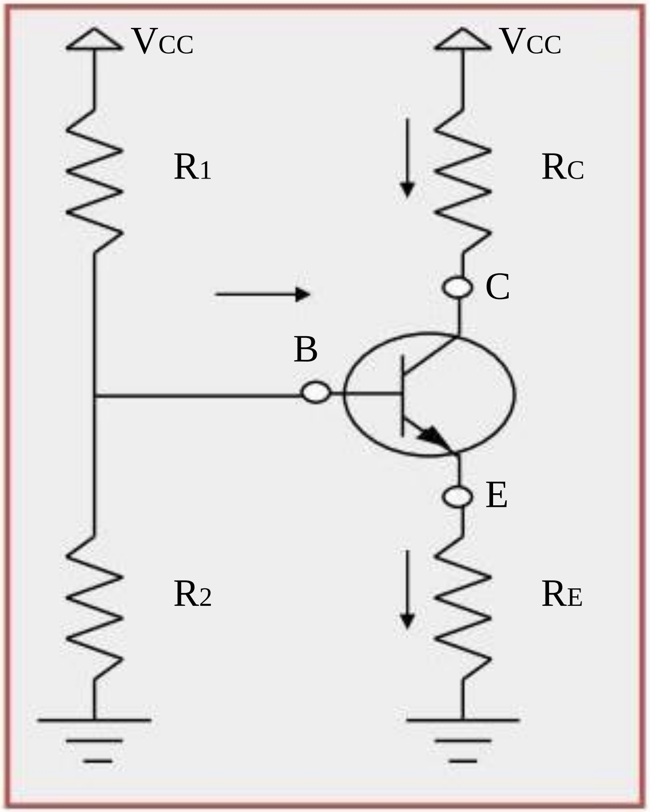
•The resistor R_f causes an AC feedback, reducing the voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

Usage: The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability is warranted.

The Potential Divider Bias Circuit

This is the most commonly used arrangement for biasing as it provide good bias stability. In this arrangement the emitter resistance ‘[redacted]vides stabilization. The resistance[redacted]ause a voltage drop in a direction so as to reverse bias the emitter junction. Since the emitter-base junction is to be forward biased, the base voltage is obtained from R_1-R_2 network. The net forward bias across the emitter base junction is equal to V_B- dc voltage drop across ‘[redacted]e base voltage is set by Vcc and R_1 and R_2. The dc bias circuit is independent of transistor current gain. In case of amplifier, to avoid the loss of ac signal, a capacitor of large capacitance is connected across R_E. The capacitor offers a very small reactance to ac signal and so it passes through the condensor.

The Potential Divider Bias Circuit

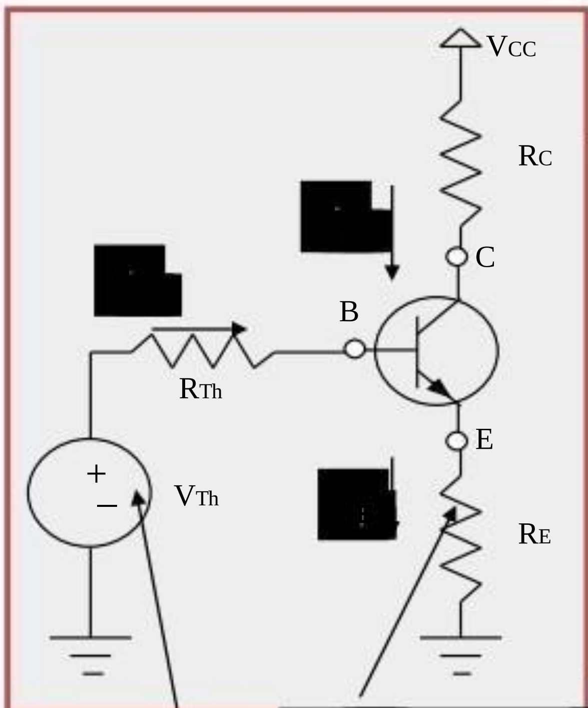


[redacted]

[redacted]

The Potential Divider Bias Circuit

Thevenin Equivalent Ci



Thevenin Equivalent Voltag

Se bias Resist

Applying KVL through input base circui

we can write

Therefore,

Diff. w. r. t. & rearranging we ge

Therefore

$$S_{Ico} = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E+R_{Th}}\right)}$$

This shows that is inversely proportional to R and it is less than (1), signifying better thermal stabili

Merits:

- Operating point is almost independent of β variation.
- Operating point stabilized against shift in temperature.

Demerits:

•As β-value is fixed for a given transistor, this relation can be satisfied either by keeping R_E fairly large, or making R1||R2 very low.

- If R_E is of large value, high V_{CC} is necessary. This increases cost as well

as precautions necessary while handling.

- If R1 || R2 is low, either R1 is low, or R2 is low, or both are low. A low R1 raises V_B closer to V_C, reducing the available swing in collector voltage, and limiting how large R_C can be made without driving the transistor out of active mode. A low R2 lowers Vbe, reducing the allowed collector current. Lowering both resistor values draws more current from the power supply and lowers the input resistance of the amplifier as seen from the base.
- AC as well as DC feedback is caused by RE, which reduces the AC voltage gain of the amplifier. A method to avoid AC feedback while retaining DC feedback is discussed below.

Usage:

The circuit's stability and merits as above make it widely used for linear circuits.

Summary

- The Q-point is the best point for operation of a transistor for a given collector current.
- The purpose of biasing is to establish a stable operating point (Q-point).
- The linear region of a transistor is the region of operation within saturation and cutoff.
- Out of all the biasing circuits, potential divider bias circuit provides highest stability to operating point.

Summary of Biasing Techniques