UNIT-2

Operation of NPN Transistor

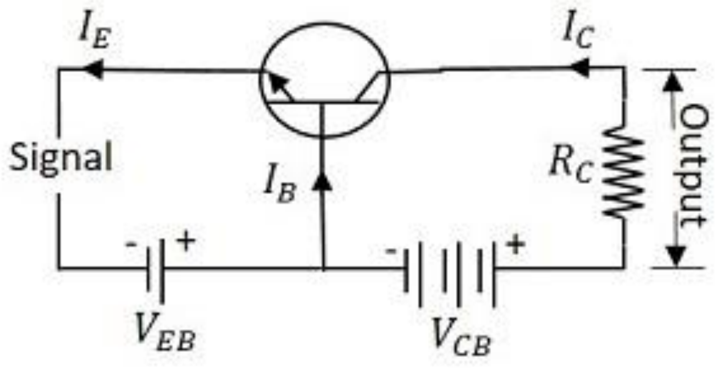
The NPN transistor is made up of n-type materials hence the majority of charge carriers are electrons that carry negative charges. When the base-emitter is forward biased then the electrons will move from the n-type region to the p-type region and the minority charge carriers (holes) will move to the p-type region. If they combine and meet together they enable a current to flow across the junction. If the junction here is reverse biased then charge carriers move away from the junction. In this case depletion region will form between two areas and there will be no current.

If the current flows between the base and emitter then the electrons will move from the emitter to the base region. If the electrons travel without recombining with holes then electrons will drift towards the collector.

Characteristics of Transistor

Input Characteristics: It gives the information about the change in input current with varying voltage having constant output voltage.
Output Characteristics: It is a plot of an output current with output voltage having constant input voltage.
Current Transfer Characteristics: This graph shows the relation between output current and input current by keeping the voltage constant.

Common-Base



Using NPN transistor

Current Amplification factor

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \; at\ constant\ V_{CB}$$

Characteristics

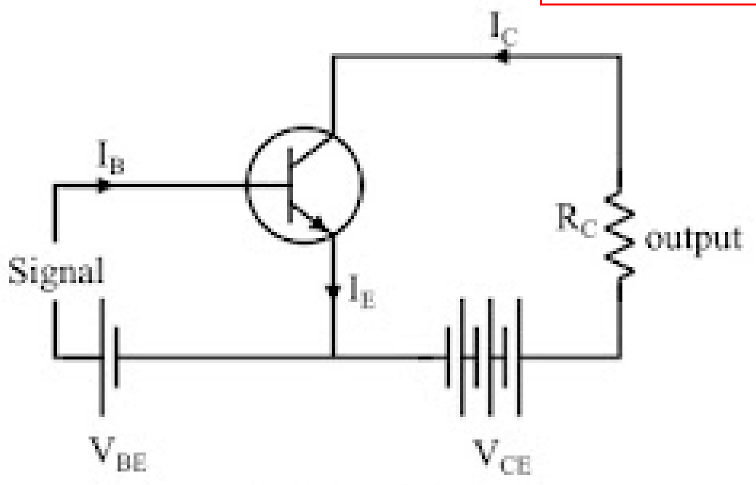
- This configuration provides voltage gain but no current gain.
- Emitter Current $\mathbf{I_E}$ is independent of Collector voltage $\mathbf{V_{CB}}$.
- As the input resistance is of very low value, a small value of V_{EB} is enough to produce a large current flow of emitter current $\mathbf{I_E}$.
- As the output resistance is of very high value, a large change in $\mathbf{V_{CB}}$ produces a very little change in collector current $\mathbf{I_C}$.
- It provides good stability against increase in temperature.
- It is used for high frequency applications.

Expression for Collector current

$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

Common-Emitter

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



Using NPN Transistor

Current Amplification factor

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

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

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

Characteristics

- It provides good current gain and voltage gain.
- It is usually used for bias stabilization methods and audio frequency applications.
- Input resistance is of very low value, a small value of $\mathbf{V_{BE}}$ is enough to produce a large current flow of base current $\mathbf{I_B}$.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \; at\ constant\ V_{CE}$$

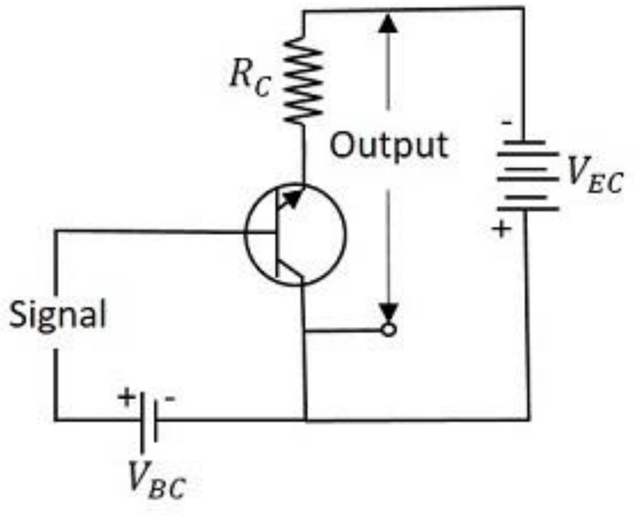
- Output resistance of CE circuit is less than that of CB circuit.

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \; at\ constant\ I_B$$

Expression for Collector current

Common-Collector

$$I_C = \alpha I_E + I_{CBO}$$



Using NPN transistor

Characteristics

- It provides current gain but no voltage gain.
- Voltage gain provided by this circuit is **less than 1**.
- Input and output signals are in phase.
- It is mostly used for impedance matching.
- Input resistance is high and the output resistance is low.

Current Amplification factor

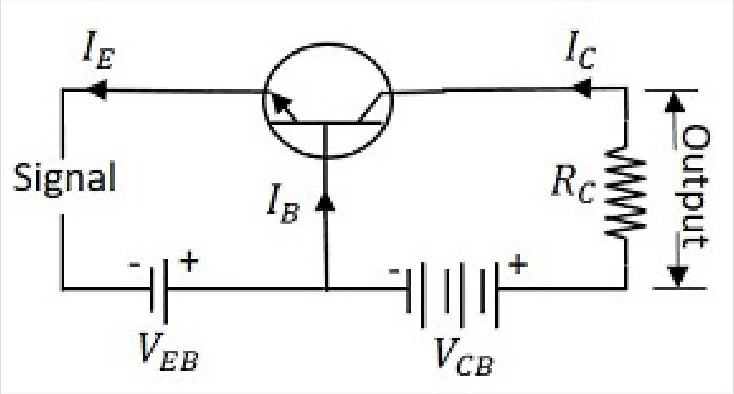
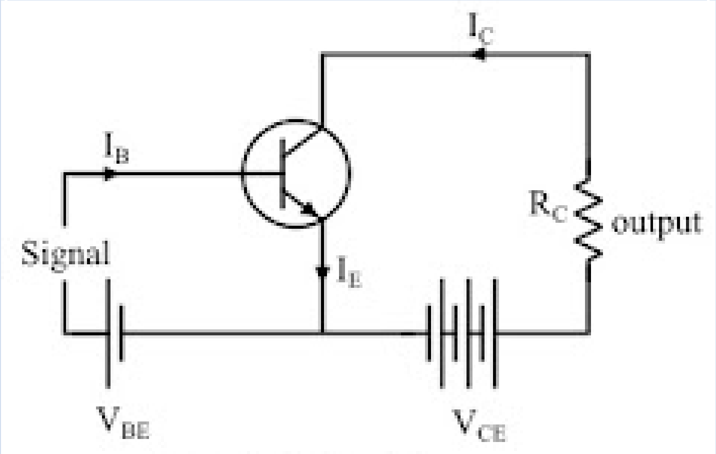
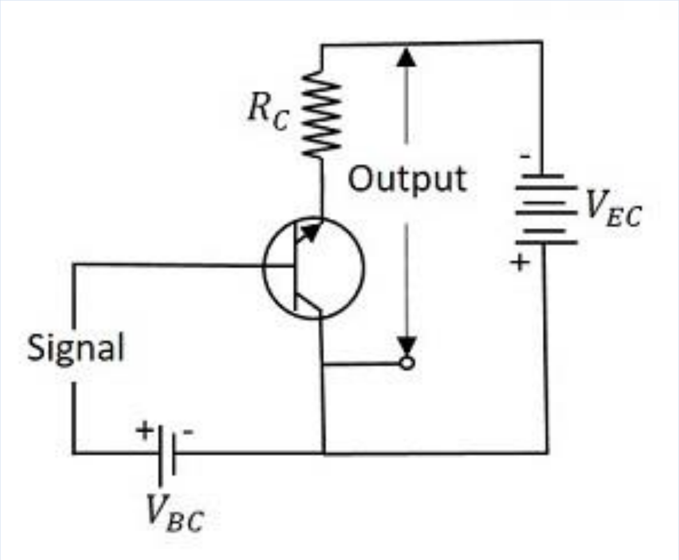
$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

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

$$\gamma = \frac{1}{1 - \alpha}$$

Expression for Collector current

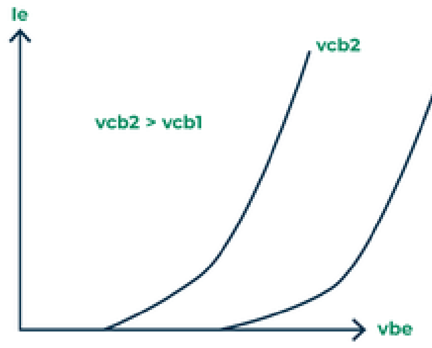
$$I_C \cong I_E = (\beta + 1) I_B + (\beta + 1) I_{CBO}$$

S.No.	Common-Base	Common-Emitter	Common-Collector
1.			
2.	Input resistance is of very low value, and Output resistance is of very high value.	Input resistance is of very low value, and Output resistance of CE circuit is less than that of CB	Input resistance is high and the output resistance is low.
3.	It provides voltage gain	It provides good current gain and voltage gain.	Voltage gain provided by this circuit is **less than 1**.
4.	No current gain.		It provides current gain
5.	It is used for high frequency applications.	It is usually used for bias stabilization methods and audio frequency applications.	It is mostly used for impedance matching.
6.		Input and output signals are in phase shift of 180°	Input and output signals are in phase

Input Characteristics:

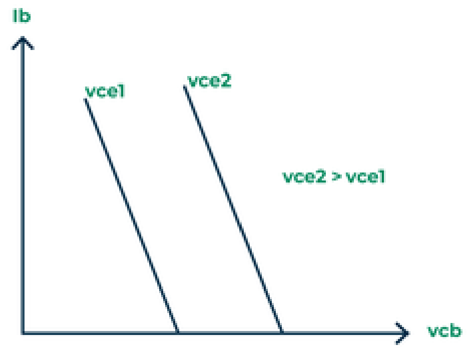
CB Configuration

By keeping collector voltage as constant



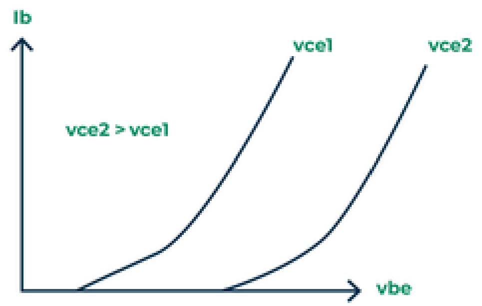
CC Configuration

keeping collector emitter voltage as constant



CE Configuration

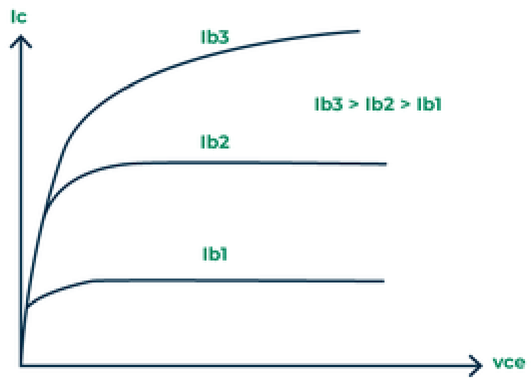
By keeping collector emitter (V_{CE}) voltage as constant.



Output Characteristics

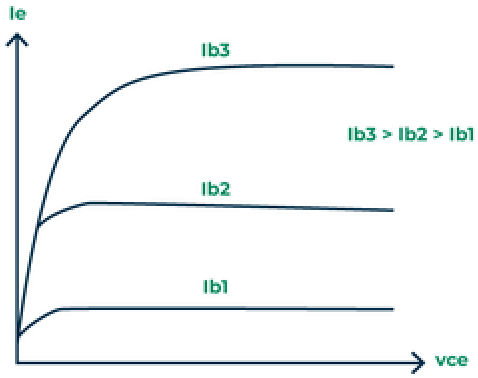
CB Configuration

By keeping I_B as constant



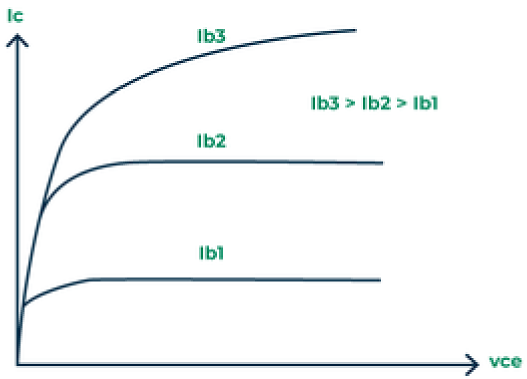
CC Configuration

keeping collector emitter voltage as constant



CE Configuration

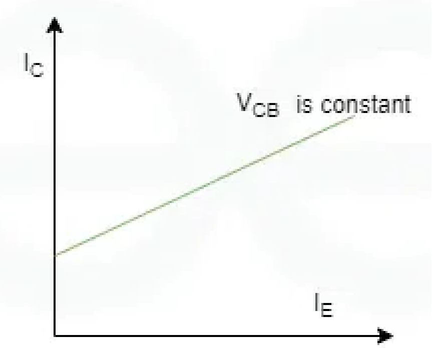
By keeping collector emitter (V_{CE}) voltage as constant.



Current Transfer Characteristics

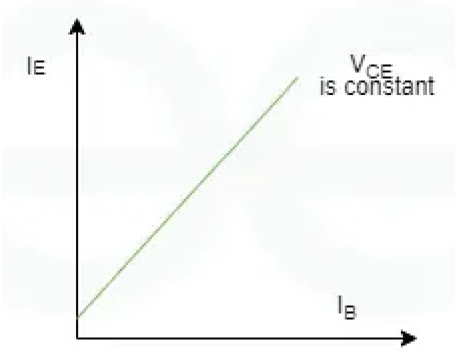
CB Configuration

By keeping I_E as constant



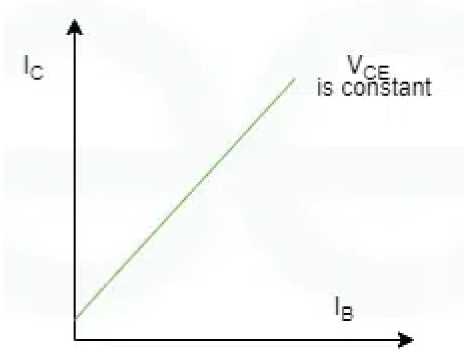
CC Configuration

keeping collector emitter voltage as constant



CE Configuration

By keeping collector emitter (V_{CE}) voltage as constant.



Advantages of Transistors Configuration

Common-Base Configuration:

- It offers low power consumption.
- The current gain(α) of this configuration is less affected by the change in temperature.

Common-Emitter Configuration:

- Common-emitter configuration has high power gain.
- This type of configuration is easy to bias and therefore offers versality to various applications.
- Common-emitter configuration produces inverted output.

Common-Collector Configuration:

- This type of configuration has voltage gain close to unity which could be used for buffering of voltage.
- Common-collector configuration has high input impedance.
- There is no phase reversal between input signal and output signal.

Disadvantages of transistors configuration

Common-Base Configuration:

- Input signal reaches power supply limits clipping of signal takes place.

Common-Emitter Configuration:

- The output signal of common-emitter signal is inverted with respect to input signal.
- large amount of power is dissipated as heat

Common-Collector Configuration:

- It is temperature-sensitive

Applications

Common-Base configuration

- It is commonly used in low-noise amplifiers.
- Photodetectors to amplify the weak received signals.
- It is also used in frequency converters

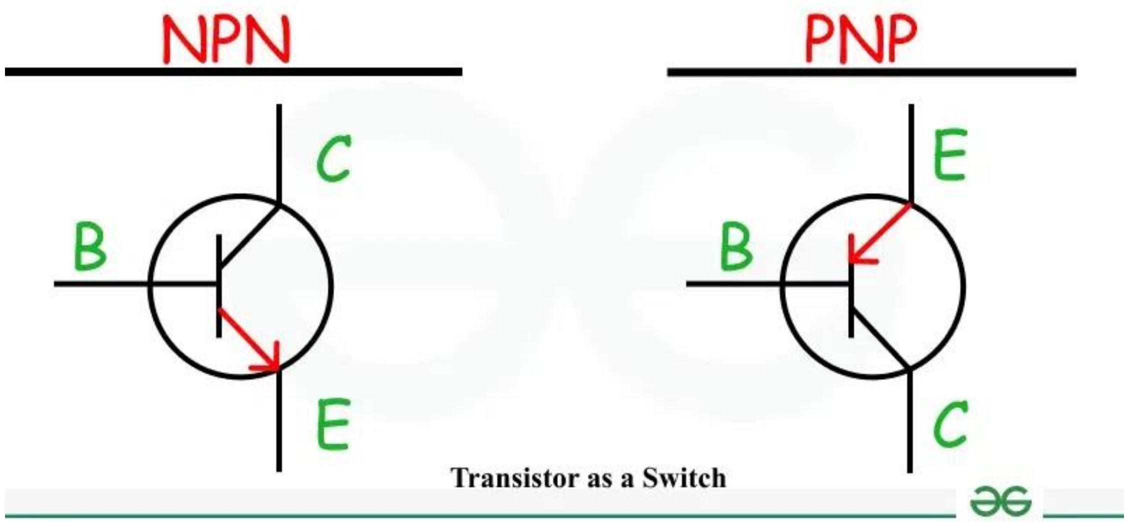
Common-Emitter Configuration

- These configurations are useful in voltage amplifiers.
- It also helps in modulation of received input signal.
- It is also useful in radio-frequency amplifiers.

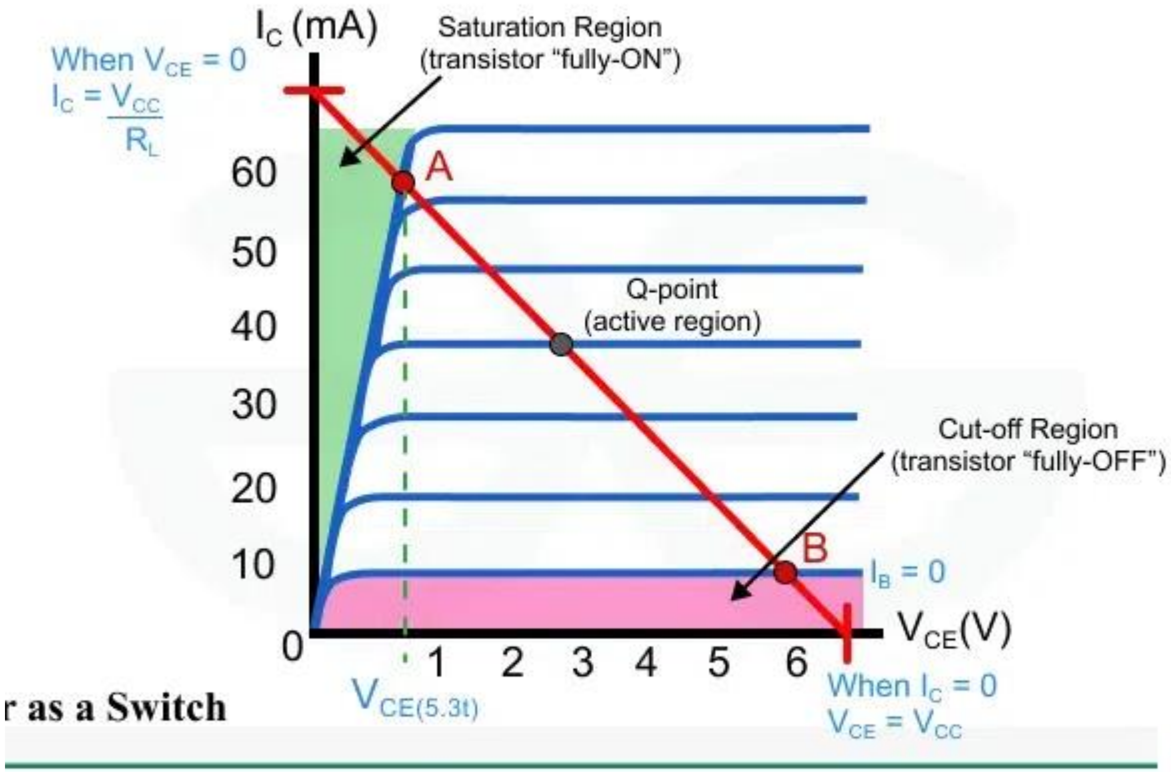
Common-Collector Configuration

- It is commonly used in voltage regulation.
- In RF applications it is used to match the impedance between different stages of a circuit.
- Common-collector configuration also finds their application in current buffers.

Transistor as a switch is used for turning ON or OFF a circuit and the transistor is used as an amplifier for amplifying the current.



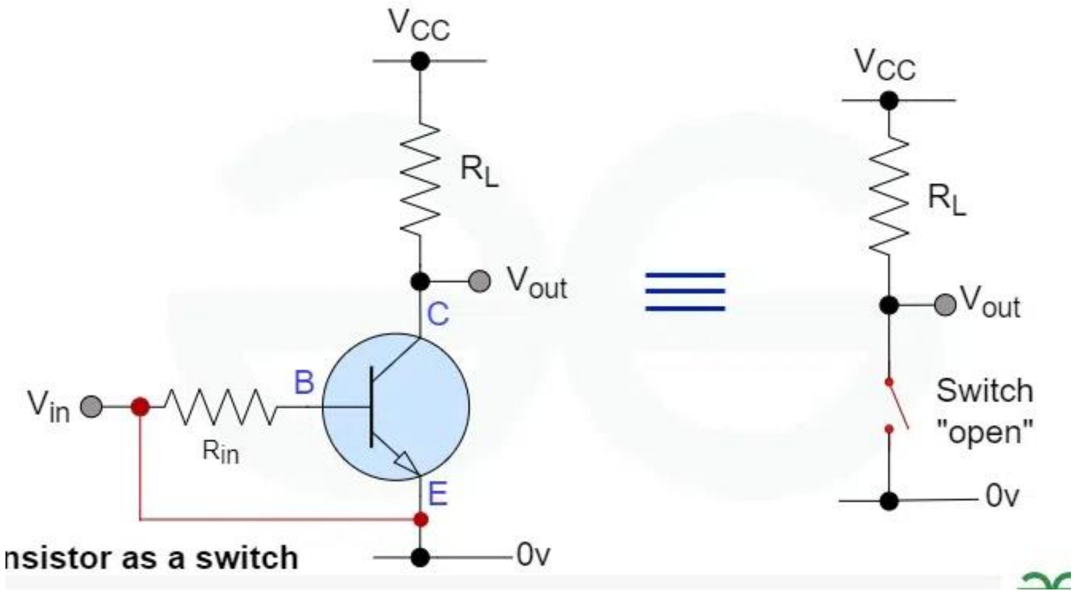
- The operating area of the transistor switch called saturation region and the cut-off Region



- A transistor can be used for switching operations or opening or closing of the circuit. It's operation generally low voltage DC is on or off by the transistor in this mode. The both type of the PNP and NPN transistor are used as switches.

Cut-off Region

- It operates under conditions of zero input base current (Ib), zero output collector current (Ic), and maximum collector voltage (Vce)

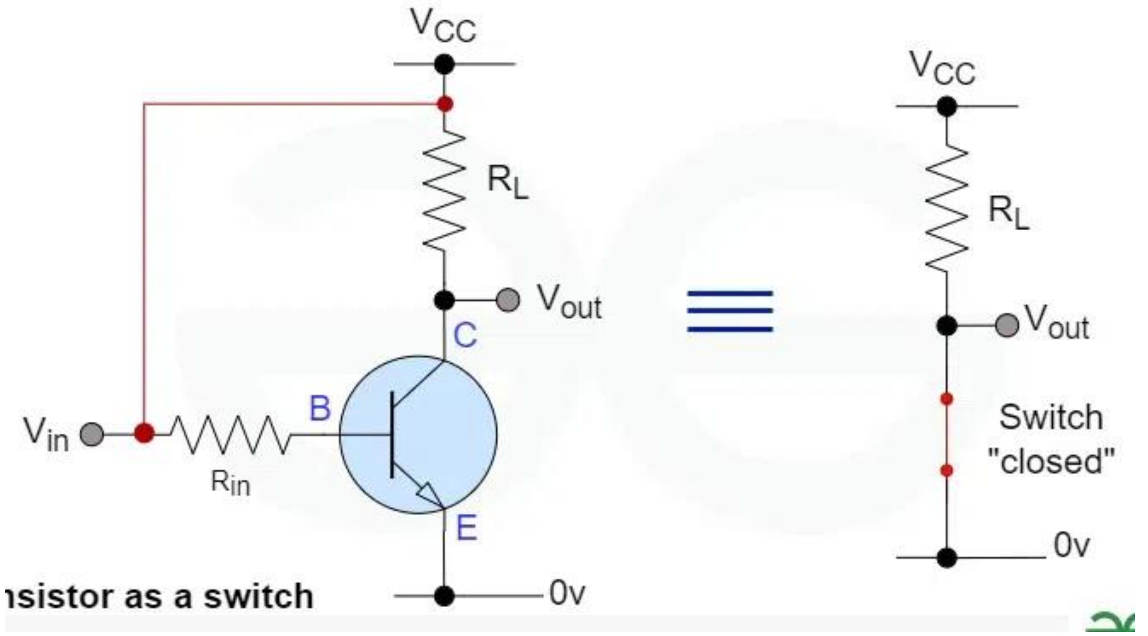


- The input and base are grounded.
- Base emitter voltage $V_{BE} < 0.7v$
- Base Emitter junctions is reversed.
- Base- collector junction us reversed biased.
- Transistor is "fully-Off" (cut off region)
- No collector current flows(I_c=0)
- Transistor operates as open switch

Saturation Region

- The maximum amount of the current is applied, which results in the maximum collector current. Maximum current flowing through the transistor so the transistor is switched "Fully ON"

- The base and input are connected to Vcc.
- Base-Emitter voltage Vbe > 0.7V.
- Base-Emitter junction is forward biased.
- Base-collector junction is forward biased.
- Transistor is "fully-On"
- Max Collector current flows (Ic=Vcc/Rl)
- Vce=0 (ideal saturation)
- Vout = Vce="0".
- Transistor operates as a closed switch.



What is Transistor Biasing ?

Transistor biasing is defined as the proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of a signal. Transistors can operate in three regions namely cut off, active and saturation region. To operate the transistor in the desired region we have to apply the external dc voltages of correct polarity and magnitude to the two junctions of the transistor. The basic purpose of transistor biasing is to keep the base-emitter junction properly forward biased and collector-base junction reverse biased during the application of signal

Need for Transistor Biasing

- ❑ For proper working it is essential to apply voltages of correct polarity across its two junctions.
- ❑ If *it is not biased correctly, it would work inefficiently and produce distortion in the output signal*.
- ❑ Operating point should bot be affected due to temperature changes and device variations.

Modes	EBJ	CBJ	Application
Cutoff	Reverse	Reverse	Switching application in digital circuits
Saturation	Forward	Forward	
Active	Forward	Reverse	Amplifier

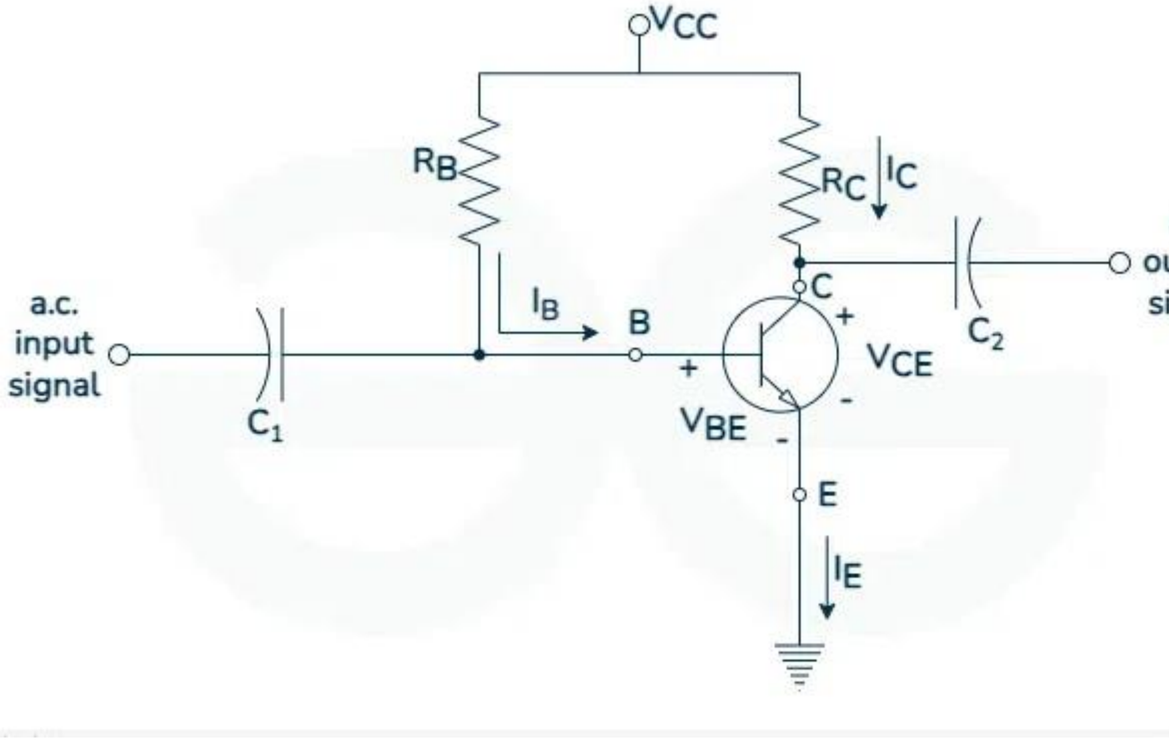
Types of Transistor Biasing

The following are the most commonly used types of transistor biasing are as below :

- **Fixed bias circuit** (Single base resistor biasing) or base bias.
- Collector to base bias circuit.
- Voltage divider bias circuit (V.D.B.) or **Self bias**.
- Emitter bias or modified fixed bias circuit.

Fixed Bias Circuit

In this, a resistance *R_B is connected between supply V_{CC} and base terminal of the transistor*. The required zero signal base current I_B is provided by V_{CC} and a single V_{CC} keeps the base emitter junction forward biased and the collector base junction reverse biased.



Base Circuit (at the input end)

*Apply **K.V.L.** to the base circuit:*

$$V_{CC}-I_BR_B-V_{BE}=0$$

$$I_BR_B=V_{CC}-V_{BE}$$

$$I_B=(V_{CC}-V_{BE})/R_B$$

$$I_B \cong V_{CC}/R_B \ (\because V_{CC}>>V_{BE})$$

- For silicon transistors V_{BE} is 0.7 V and for germanium transistors V_{BE} is 0.3 V.
- In this circuit, the supply V_{CC} is of a fixed value. As the resistance R_B is selected, I_B is also fixed. Hence this circuit is called as fixed bias circuit.

Collector Circuit (at the output end)

Now apply K.V.L. to the collector circuit.

$V_{CC}-I_CR_C-V_{CE}=0$

$V_{CE}=V_{CC}-I_CR_C$

$I_CR_C=V_{CC}-V_{CE}$

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

The collector current in CE configuration is given as, $I_C=\beta I_B+I_{CEO}$

where $I_{CEO}\rightarrow$ **Leakage current** $I_C=\beta I_B$ $(\because \beta I_B>>I_{CEO})$

Advantages of Fixed Biased Circuit

- It is a simple circuit.
- The operating point can be fixed anywhere in the active region of the characteristics by simply changing the value of R_B.
- No loading effect as no resistor is present at base-emitter junction.
- Due to their *simplicity fixed bias circuits are cost effective*.

Disadvantages of Fixed Biased Circuit

- *Poor thermal stability*.
- Since $I_C = \beta I_B$ is already fixed. I_C depends on β which is different for same type of transistor and shifts the operating point.
- Adjusting the operating point over a wide range may be challenging with fixed bias, limiting its suitability for certain applications.
- *Potential for thermal runaway.*

Voltage Divider Bias Circuit

The voltage divider is formed by R_1 and R_2. The voltage drop across R_2 forward biases the base emitter junction. The R_1 and R_2 resistor act as a voltage divider giving a fixed voltage at point B which is base. *This is the most widely used biasing method that provides biasing and stabilization to a transistor*.

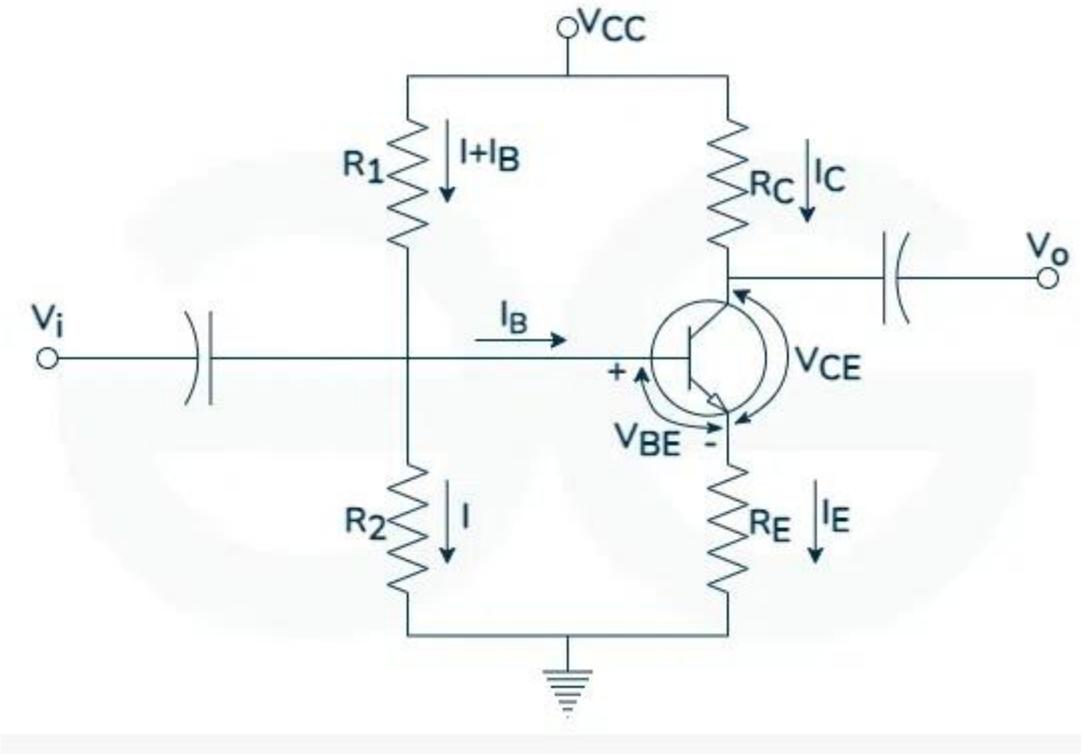


Fig. Voltage Divider Bias Circuit

Base Circuit:

Voltage across R_2 is the base voltage V_B.

Apply voltage divider to this circuit

$\therefore V_B=(V_{CC}R_2)/(R_1+R_2)$

Collector Circuit: Voltage across R_E is V_E and can be obtained as

$V_E=I_ER_E=V_B-V_{BE}$

$I_E=(V_B-V_{BE})/(R_E)$

Apply K.V.L. $V_{CC}=I_CR_C+V_{CE}+V_E$

$V_{CE}=V_{CC}-I_CR_C-I_ER_E$

Advantages of Voltage Divider Base Circuit

- I_C in this circuit is almost independent of transistor parameters.
- The resistor employed in the emitter provides stabilization.
- Flexibility in adjusting operating point.
- Moderate sensitivity to power supply changes.

Disadvantages of Voltage Divider Base Circuit

- Due to the increased complexity, it tend to be more expensive.
- It can lead to reduction in overall circuit efficiency due to the power dissipation.

Bias Stabilisation

Bias Stabilization

The stability of a system is a measure of the sensitivity of a network to variations in its parameter. B increases with increase in temperature . Magnitude of V_{BE} decreases about 7.5 mV per degree Celsius (°C) increase in temperature. I_{CO}(reverse saturation current): doubles in value for every 10°C increase in Temperature

Stability Factors, $S(I_{CO})$, $S(V_{BE})$, and $S(\beta)$

A stability factor,S, is defined for each of the parameters affecting bias stability as listed below:

$$S(I_{CO}) = \Delta I_C / \Delta I_{CO}$$

$$S(V_{BE}) = \Delta I_C / \Delta V_{BE}$$

$$S(\beta) = \Delta I_C / \Delta \beta$$

In each case, the delta symbol signifies change in that quantity.

Bias stabilization

- If I_C increases due to change in temp. or β

↓

- Then I_E increases

↓

- Hence drop across R_E increases ($V_E = I_E R_E$)

↓

- But V_B is constant. Hence V_{BE} decreases.

↓

- Hence I_B decreases.

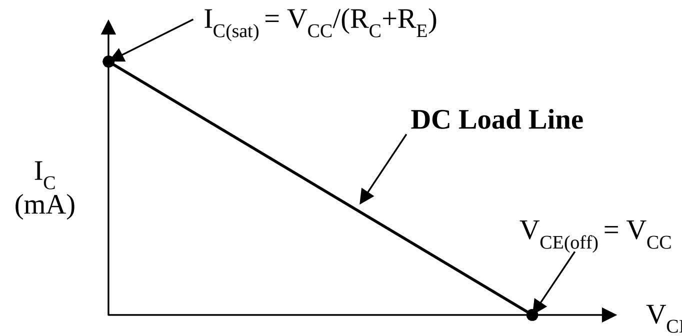
↓

- Hence I_C also deceases. Thus the compensation for increase in I_C is achived.

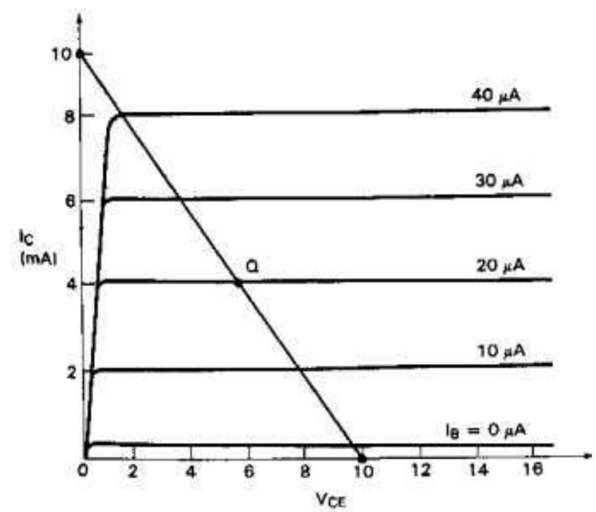
DC Load Line

•The straight line is know as the **DC load line**

•Its significance is that regardless of the behavior of the transistor, the collector current I_C and the collector-emitter voltage V_{CE} must always lie on the load line, depends ONLY on the V_{CC}, R_C and R_E



•(i.e. The dc load line is a graph that **represents all the possible combinations of I_C and V_{CE} for a given amplifier**. For every possible value of I_C, and amplifier will have a corresponding value of V_{CE}.)



What is $I_{C(sat)}$ and $V_{CE(off)}$?

•It must be true at the same time as the transistor characteristic. Solve two condition using simultaneous equation

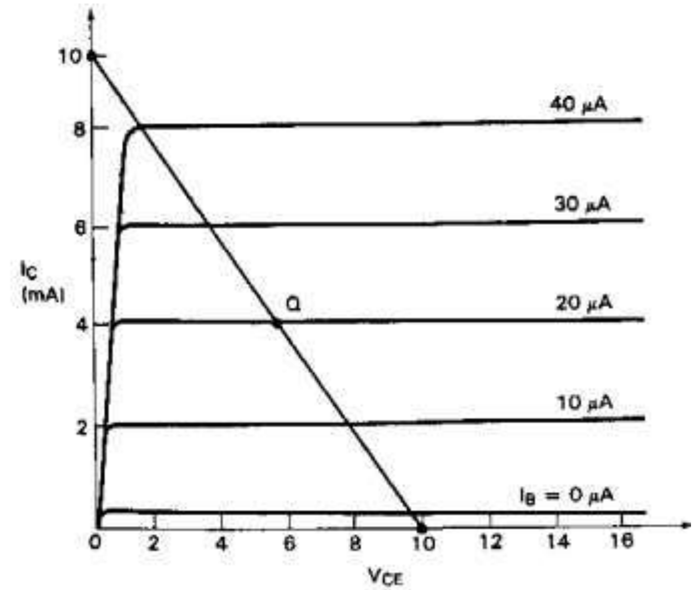
→ graphically → **Q-point !!**

Q-Point (Static Operation Point)

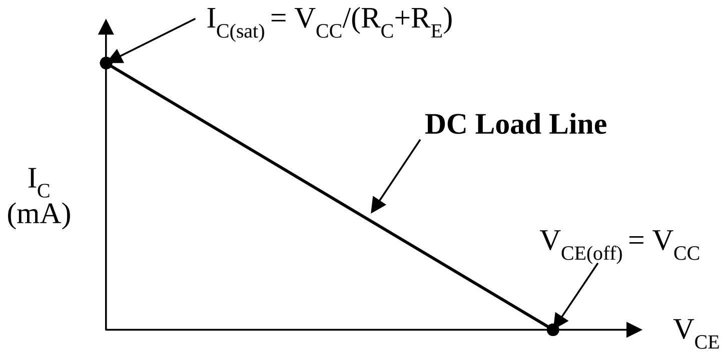
- When a transistor does not have an **ac input**, it will have **specific dc values** of I_C and V_{CE}.
- These values correspond to a specific point on the **dc load line**. This point is called the ***Q-point***.
- The letter ***Q*** corresponds to the word (Latent) **quiescent**, meaning **at rest**.
- A quiescent amplifier is one that has no ac signal applied and therefore has constant dc values of I_C and V_{CE}.

Q-Point (Static Operation Point)

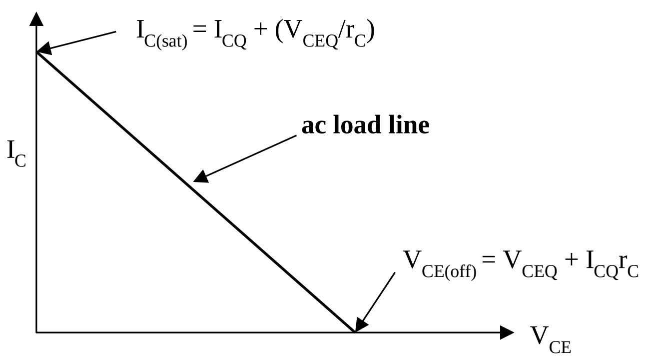
- The intersection of the dc bias value of I_B with the dc load line determines the *Q*-point.
- It is desirable to have the *Q*-point centered on the load line. Why?
- When a circuit is designed to have a centered *Q*-point, the amplifier is said to be midpoint biased.
- Midpoint biasing allows optimum ac operation of the amplifier.

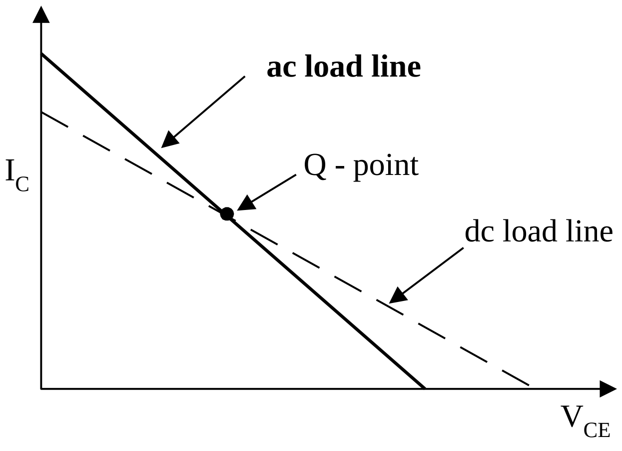


AC Load Line



- The ac load line of a given amplifier will **not follow** the plot of the dc load line.
- This is due to the dc load of an amplifier is different from the ac load.





AC Load Line

What does the ac load line tell you?

- The ac load line is used to tell you the maximum possible output voltage swing for a given common-emitter amplifier.
- In other words, the ac load line will tell you the maximum possible peak-to-peak output voltage (V_{pp}) from a given amplifier.
- This maximum V_{pp} is referred to as the **compliance** of the amplifier.

(AC Saturation Current $I_{c(sat)}$, AC Cutoff Voltage $V_{CE(off)}$)