ELECTRONIC DEVICES & CIRCUITS
Module 3

AMPLIFIERS- Operating point & Stability Factor
S3 CSE KTU

prepared by

Anjana Devi

Amplification

•The basic function of transistor is to do amplification.

•The weak signal is given to the base of the transistor and amplified output is obtained in the collector circuit.

•One important requirement during amplification is that only the magnitude of the signal should increase and there should be no change in signal shape.

•This increase in magnitude of the signal without any change in shape is known as faithful amplification.

•This is achieved through transistor biasing.

•Wave form distortion will occur if the transistor is not properly biased.

.

Common Emitter configuration is the most common type of amplifier.

• The amplification happens in the active region where Base – Emitter junction is forward biased and Collector – Base junction is reverse biased.

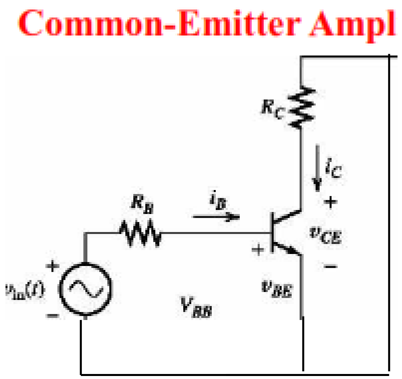
Without the correct bias, the transistor will not operate properly in the active region and causes its output to distort.

For faithful amplification, a transistor must satisfy the following conditions :

1.Minimum proper base-emitter voltage (V_{BE}) at any instant.
2. Proper zero signal collector current.
3. Minimum proper collector-emitter voltage (V_{CE}) at any instant.

1. Proper Minimum Base-Emitter Voltage

For faithful amplification, the base-emitter voltage (V_{BE}) should be larger than the cut-in voltage of BE junction: 0.5 V for Ge transistor and 0.7 V for Si transistor. This is to overcome the potential barrier.



If the base-emitter voltage is less than this value for any part of the applied signal, the transistor does not conduct and that part of the signal will be cut-off which will result in unfaithful amplification

Unfaithful amplification

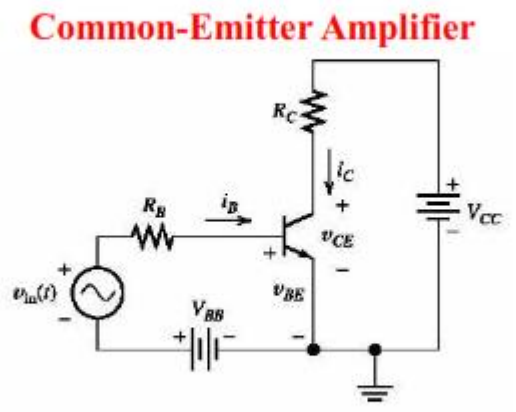
G

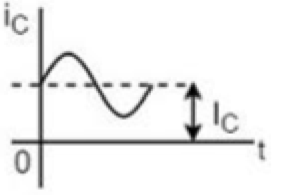
During the positive half-cycle of the applied signal, base-emitter junction is forward biased. As v_{in} increases, the ac current i_B also increases by maintaining the shape. Since $i_C = h_{FE}\, i_B$ large collector current flows but maintains the shape. Hence the positive half-cycle of the signal is amplified.

During the negative half-cycle, the base-emitter junction is reverse biased and hence no current flows in the circuit. Therefore, there is no output current i_C and no o/p voltage during the negative half-cycle of the signal.
Thus we will get an amplified output of the signal with no negative half cycles, which is unfaithful amplification.

Faithful Amplification

Now if a battery source V_{BB} is introduced in the base circuit as shown in the figure below.





The magnitude of the battery should be such that, it keeps the input circuit forward biased for any value of the applied signal during both positive and negative half cycles.

During the positive half-cycle of the applied signal, input circuit is more forward biased and hence more collector current flows in the output circuit due to rise in i_B

During the negative half-cycle, the effective total input voltage decreases and will be minimum when i/p is at negative peak. But even then the BE junction is FB due to proper selection of V_{BB} .The collector current decreases but the negative half-cycle also appears in the output. Thus faithful amplification is achieved

2. Proper Zero Signal Collector Current

When no signal is applied, a d.c. current I_C flows in the collector circuit due to V_{BB}, known as zero signal collector current.

The zero signal collector current value should be at least equal to maximum collector current due to signal alone

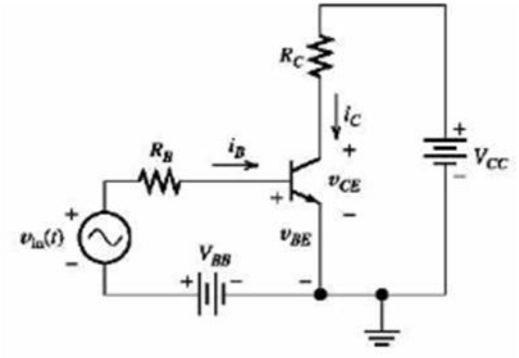
Unfaithful amplification- No V_{BB} **Vcc bias-** The zero signal collector current value is zero

During the positive half-cycle of the applied signal, base-emitter junction is forward biased and hence base current as well as large collector current flows in the circuit. Hence the positive half-cycle of the signal is amplified.
During the negative half-cycle, the base-emitter junction is reverse biased and hence no current flows in the circuit. Therefore, there is no output during the negative half-cycle of the signal.
Thus we will get an amplified output of the signal with no negative half cycles, which is unfaithful amplification.

2. Proper Zero Signal Collector Current contd…

Faithful amplification- V_{BB} **and Vcc bias applied-** The zero signal collector current value is sufficient to provide Ic even in the worst case of input negative peak.

Common-Emitter Amplifier



When no signal is applied, a d.c. current I_C flows in the collector circuit due to V_{BB}, known as zero signal collector current.

During the positive half-cycle of the applied signal, input circuit is more forward biased and hence more collector current flows in the output circuit.

However, during the negative half-cycle, the input circuit is less forward biased and collector current decreases but never reduces to zero. Hence, the negative half-cycle also appears in the output.

3. Proper Minimum Collector-Emitter Voltage

For faithful amplification, the collector-emitter voltage should be larger than 0.5 V for Ge transistor and 1 V for Si transistor. This is known as knee voltage.

When V_{CE} is less than this value , the collector-emitter junction is not properly reverse biased. Then the collector cannot attract the electrons which are emitted by the emitter and they will flow towards base which increases the base current. Thus the value of β falls.

This causes a decrease in the collector current . Hence, the applied signal will not be amplified properly and results in unfaithful amplification.

So if V_{CE} is greater than V_{KNEE} the collector-base junction is properly reverse biased and the value of β remains constant, resulting in faithful amplification.

Transistor Biasing fundamentals-

For faithful amplification, a transistor amplifier must satisfy the three conditions.

1.Proper zero signal collector current.

2.Minimum proper base-emitter voltage (V_{BE}) at any instant.

3.Minimum proper collector-emitter voltage (V_{CE}) at any instant.

The fulfilment of these conditions is known as transistor biasing .

The basic purpose of transistor biasing is to keep the base-emitter junction forward biased and collector- base junction reverse biased at any instant of the applied signal so that the transistor remains in the active region

This can be achieved with a bias battery or associating a circuit with a transistor.

• The latter method is more efficient and is frequently employed.

• The circuit which provides transistor biasing is known as biasing circuit.

• It may be noted that transistor biasing is very essential for the proper operation of transistor in any circuit

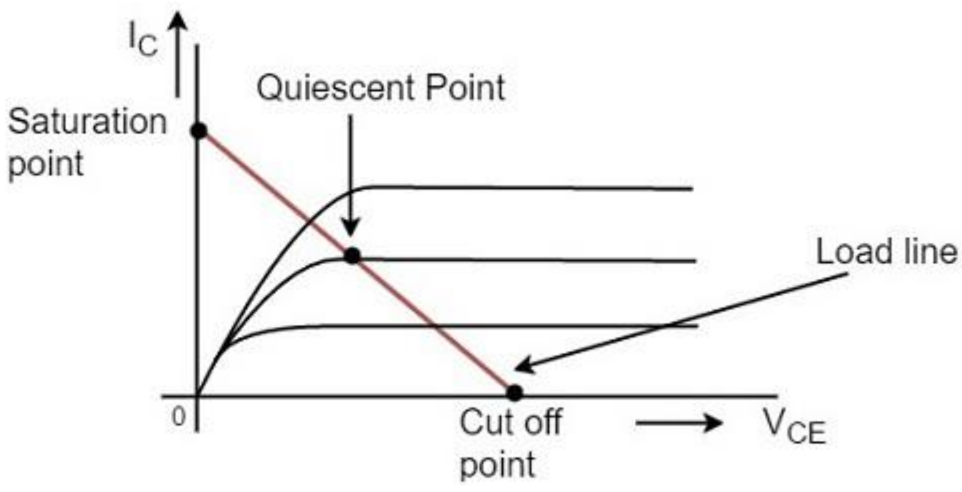
If appropriate DC voltages and currents are given by external sources, so that BJT operates in active region and superimpose the AC signals to be amplified, then the problem of distortion can be avoided. The given DC voltage and currents are so chosen that the transistor remains in active region for entire input AC cycle. Hence DC biasing is needed.

Relevance of Load line & Q-point/ operating point

For faithful amplification the DC load line plays an important role

When a line is drawn joining the saturation and cut off points, such a line can be called as **Load line**. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**.
This operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in the active region.

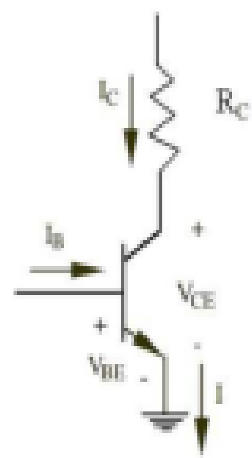
The operating point should not get disturbed as it should remain stable to achieve faithful amplification. Hence the quiescent point or Q-point is the value where the **Faithful Amplification** is achieved

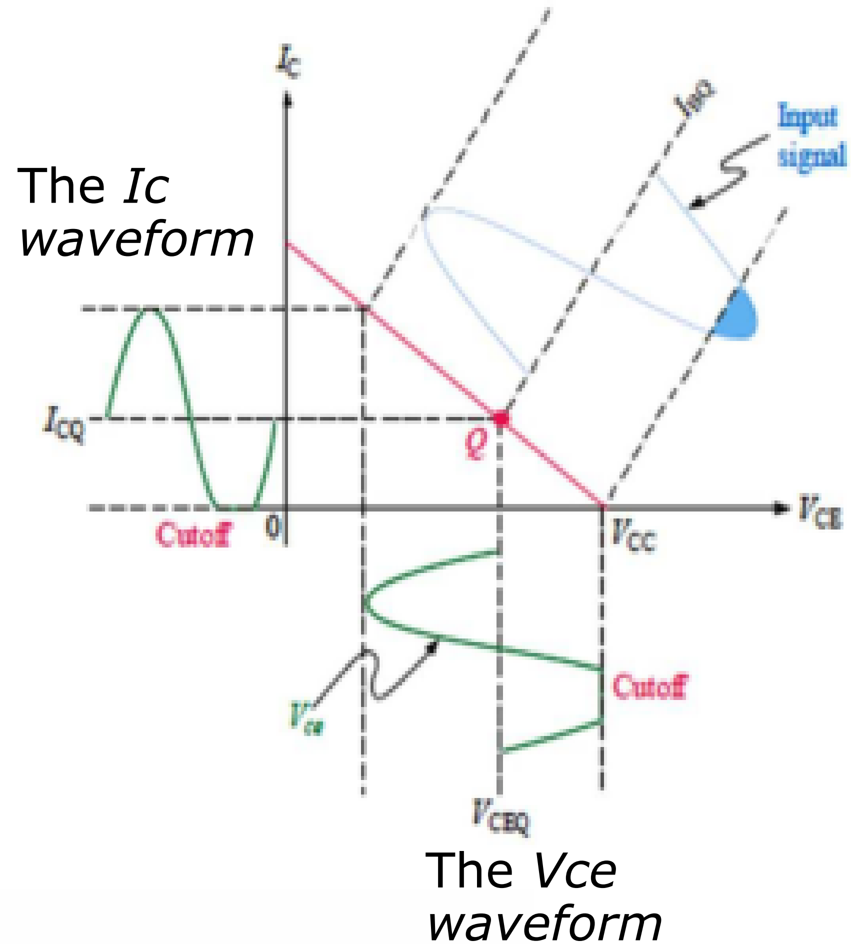


The operating point is so chosen such that it lies in the **active region** and it helps in the reproduction of complete signal without any loss

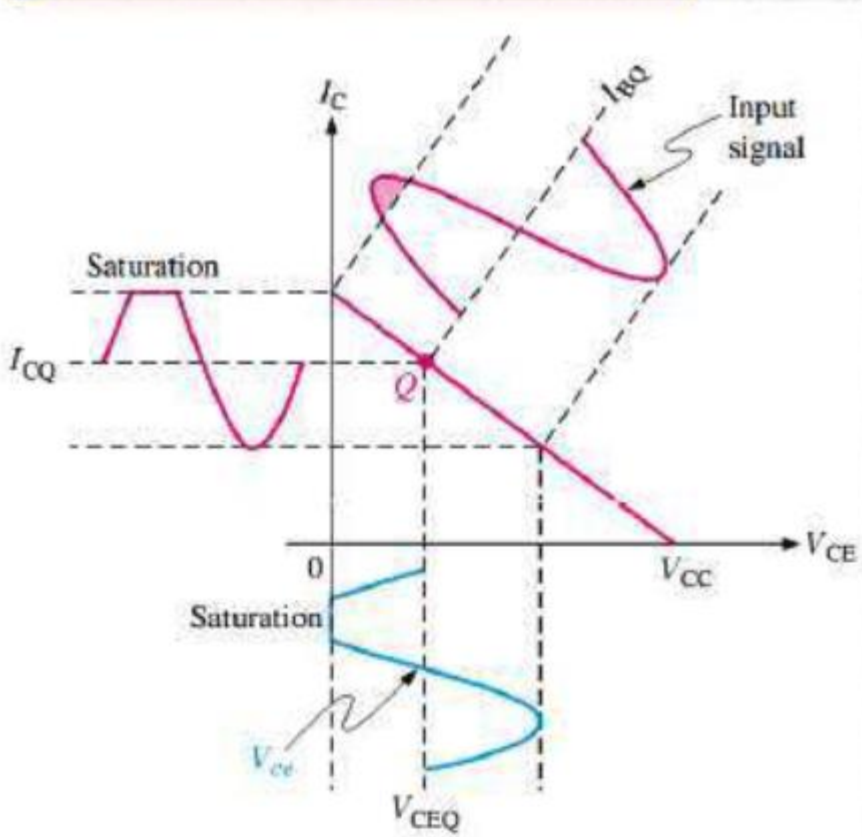
WAVEFORM DISTORTION

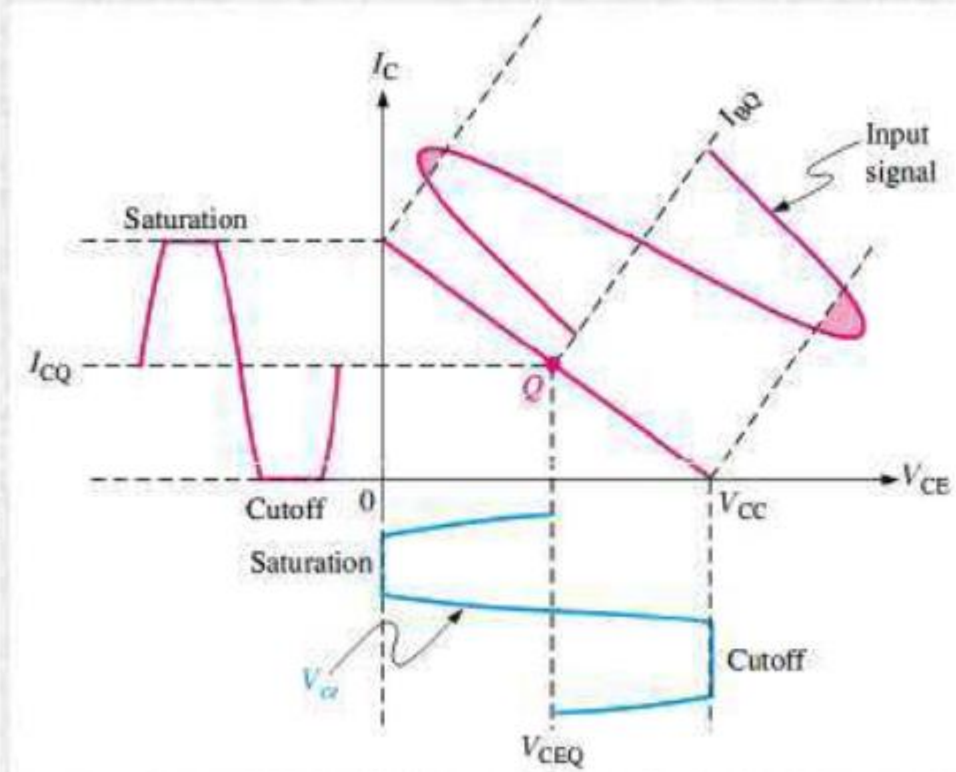
- A signal that swings outside the active region will be clipped.
- For example, the bias has established a low *Q point*.
- As a result, the signal will be clipped because it is too close to cutoff.





Waveform Distortion



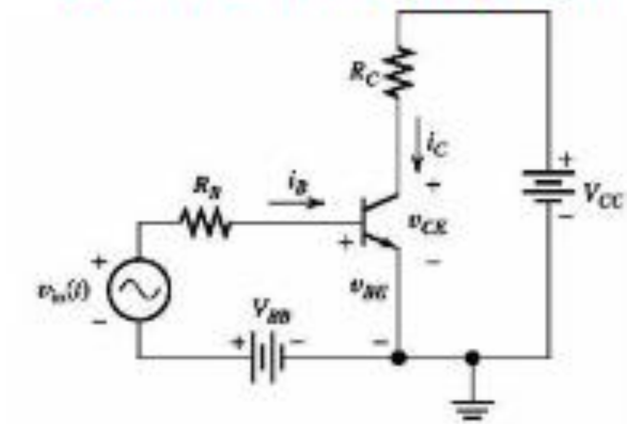


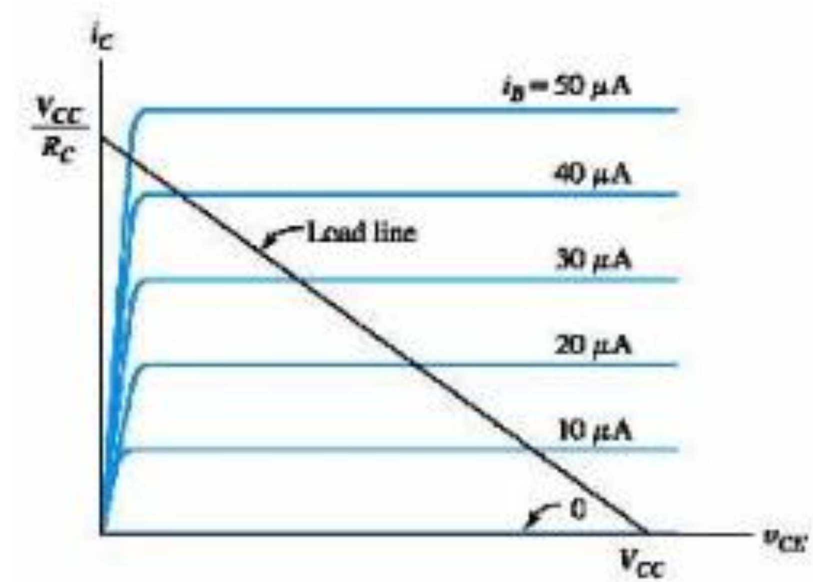
High *Q*- point. The signal will be clipped because it is too close to saturation.

Input signal too large. The signal will be clipped from both sides.

BJTs – LOAD LINE ANALYSIS

Common-Emitter Amplifier





Applying KVL in Output loop

$$V_{CC} = R_C i_C + v_{CE}$$

Saturation point
$v_{CE} = 0$; ic = Vcc/Rc

Cut-off point
ic = 0; v_{CE} = Vcc

As Q-point varies
Cut-off point
ic = 0; v_{CE} = Vcc

Transistor Biasing- Need

1.The transistor biasing is required for faithful amplification.

For faithful amplification, a transistor amplifier must satisfy the three conditions.

1.Proper zero signal collector current.
2.Minimum proper base-emitter voltage (V_{BE}) at any instant.
3.Minimum proper collector-emitter voltage (V_{CE}) at any instant.

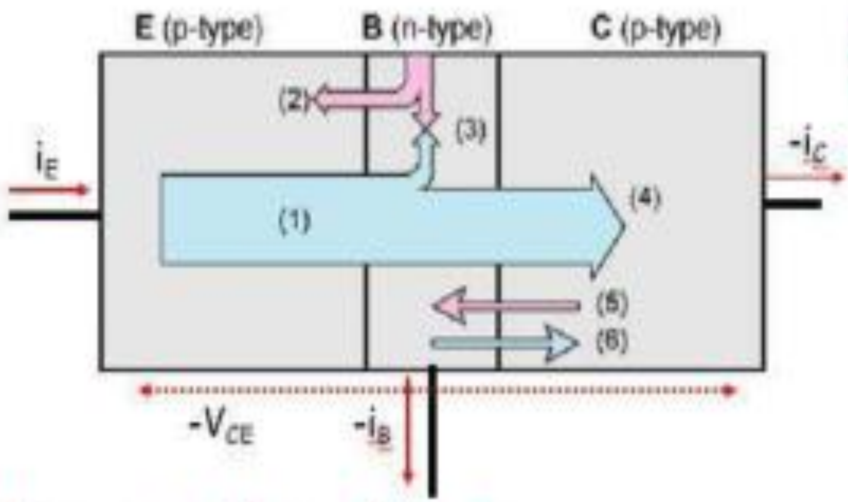
2. Biasing is required for ensuring that Q-point is placed midway in the active region to avoid waveform distortion.

3.Biasing circuits are necessary to stabilize the transistor's operating point irrespective of variations in I_{co}, β, V_{be} which vary because of

1) varying temperature.
2) replacement of device

Current Flow in BJT

pnp BJT



1. Injected h^+ current from E to B
2. e^- injected across the forward-biased EB junction (current from E toB)
3. e^- supplied by the B contact for recombination with h^+ (recombination current)
4. h^+ reaching the reverse-biased C junction

5,6. Thermally generated e^- & h^+ making up the reverse saturation current of the C junction

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$

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

I_{CBO} = collector Base current when emitter is open

Start with,

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

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

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

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

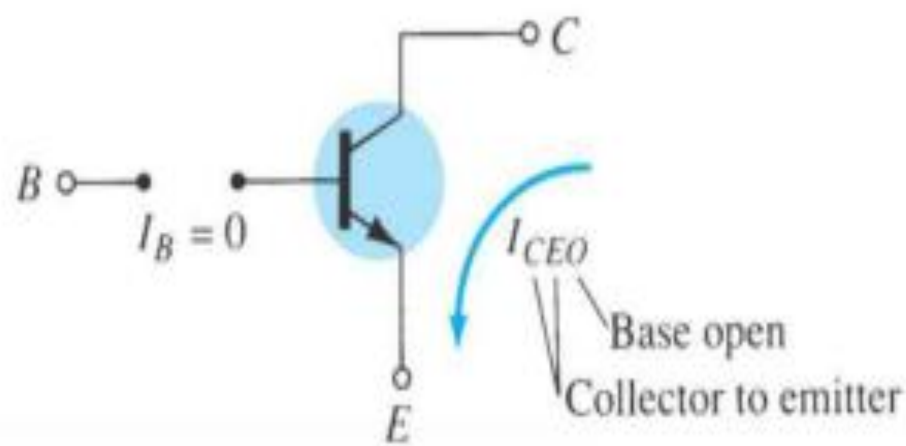
Now open the base lead which makes $I_B = 0$

So,

$$I_{CEO} = \frac{I_{CBO}}{(1-\alpha)}$$

Emitter lead open

Base lead open



Stabilization

For a transistor to be operated as a faithful amplifier, the operating point should be stabilized.

The process of making the operating point independent of 1)temperature changes or 2) variations in transistor parameters is known as **Stabilization**. Stabilization is achieved through biasing.
Once the stabilization is achieved, the values of I_C and V_{CE} become
1) independent of temperature variations 2) replacement of transistor.

A good biasing circuit helps in the stabilization of operating point.

Factors affecting the operating point

1) **Effect of temp:** The main factor that affect the operating point is the temperature. The operating point shifts due to change in temperature

- **Temp** affects the transistor parameters I_{CBO}, β, V_{BE}

- ***I_{CBO} gets doubled (for every 10^o rise)***
- ***V_{BE} decreases by 2.5mv (for every 1^o rise)***
- ***β increases with temperature since Ic increases with temp and β depends on Ic. The relation of β variation with temp will be provided by the manufacturer.***

So the important problem which affects the operating point is temperature. Hence operating point should be made independent of the temperature so as to achieve stability. To achieve this, biasing circuits are introduced.

Factors affecting the operating point contd..

2) Variations in transistor parameters.

- **The value of β and V_{BE} are not exactly the same for any two transistors even of the same type.**

- **When a transistor is replaced by another of the same type, these variations change the operating point.**

- **This necessitates to stabilise the operating point i.e. to hold I_C constant irrespective of individual variations in transistor parameters.**

Need for Stabilization

The net result of these increase in I_{CBO}, β is that, Ic increases, shifting the operating point in the upward direction towards saturation region. i.e. Q-point is not stable against temperature variation.

This causes distortion in the output

Stabilization of the operating point has to be maintained due to the following reasons.

- Temperature dependence of I_C
- Individual variations in transistor parameters due to device replacement
- Thermal runaway

- **(i) Temperature dependence of I_C**
- **The collector current I_C for CE circuit is given by:**

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

- **The collector leakage current I_{CBO} is greatly influenced (especially in germanium transistor) by temperature changes.**
- **A rise of 10°C doubles the collector leakage current which may be as high as 0.2 mA for low powered germanium transistors.**
- **As biasing conditions in such transistors are generally so set that zero signal I_C = 1mA, therefore, the change in I_C due to temperature variations cannot be tolerated.**
- **This necessitates to stabilise the operating point i.e. to hold I_C constant inspite of temperature variations.**

- (ii) **Individual variations.**
- The value of β and V_{BE} are not exactly the same for any two transistors even of the same type.
- Further, V_{BE} itself decreases when temperature increases.
- When a transistor is replaced by another of the same type, these variations change the operating point.
- This necessitates to stabilise the operating point i.e. to hold I_C constant irrespective of individual variations in transistor parameters.

- (iii) <u>Thermal runaway</u>

The collector current for a CE configuration is given by :

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

- The collector leakage current I_{CBO} is strongly dependent on temperature.
- The flow of collector current produces heat within the transistor.
- This raises the transistor temperature and if no stabilisation is done, the collector leakage current I_{CBO} also increases.
- It is clear from expression that if I_{CBO} increases, the collector current I_C increases by $(\beta + 1) I_{CBO}$.
- The increased I_C will raise the temperature of the transistor even further, which in turn will cause I_{CBO} to increase.

Thus the whole cycle repeats again. Such cumulative increase in Ic will cause

1) **Large Shift in the operating point into the saturation region.**

2)

- This effect is cumulative and in a matter of seconds, the collector current may become very large, causing the transistor to burn out.
- The self-destruction of an unstabilised transistor is known as thermal runaway.
- In order to avoid thermal runaway and consequent destruction of transistor, it is very essential that operating point is stabilised i.e. I_C is kept constant.
- In practice, this is done by causing I_B to decrease automatically with temperature increase by circuit modification.
- Then decrease in βI_B will compensate for the increase in $(\beta + 1) I_{CBO}$, keeping I_C nearly constant.

The extent to which the stabilization of transistor is successful is measured by stability factor.

STABILITY FACTOR

- It is desirable and necessary to keep I_C constant in the face of variations of I_{CBO} (sometimes represented as I_{CO}).
- The extent to which a biasing circuit is successful in achieving this goal is measured by stability factor S.
- It is defined as under :
- The rate of change of collector current I_C w.r.t. the collector leakage current *I_{CO} at constant β and I_B is called stability factor i.e.

$$\text{Stability factor, } S = \frac{dI_C}{dI_{CO}} \text{ at constant } I_B \text{ and } \beta$$

- The stability factor indicates the change in collector current I_C due to the change in collector leakage current I_{CO}.
- Thus a stability factor 50 of a circuit means that I_C changes 50 times as much as any change in I_{CO}.
- In order to achieve greater thermal stability, it is desirable to have as low stability factor as possible.
- The ideal value of S is 1 but it is never possible to achieve it in practice.
- Experience shows that values of S exceeding 25 result in unsatisfactory performance.
- The general expression of stability factor for a C.E. configuration can be obtained as under:

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

** Differentiating above expression *w.r.t.* I_C, we get,

** Assuming β to be independent of I_C

$$1 = \beta \frac{dI_B}{dI_C} + (\beta + 1) \frac{dI_{CO}}{dI_C}$$

$$1 = \beta \frac{dI_B}{dI_C} + \frac{(\beta + 1)}{S} \quad \left[\because \frac{dI_{CO}}{dI_C} = \frac{1}{S}\right]$$

$$S = \frac{\beta + 1}{1 - \beta\left(\frac{dI_B}{dI_C}\right)}$$

- For a BJT, there exists two more stability factors, which relate to the temperature stability of base-emitter voltage V_{BE} and the forward current gain factor β.
- The two stability factors are simply defined as the partial derivatives

$$S(V_{BE}) = \frac{\partial I_C}{\partial V_{BE}} \qquad S(\beta_F) = \frac{\partial I_C}{\partial \beta_F}.$$

CALCULATION OF STABILITY FACTORS

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

$$S \equiv \frac{\partial I_C}{\partial I_{CO}}$$

- **Stability Factor S':- The variation of I_C with V_{BE} is given by the stability factor S defined by the partial derivative:**

$$S' \equiv \frac{\partial I_C}{\partial V_{BE}} \approx \frac{\Delta I_C}{\Delta V_{BE}}$$

- **Stability Factor S″:- The variation of I_C with respect to β is represented by the stability factor, S'', given as:**

$$S'' \equiv \frac{\partial I_C}{\partial \beta} \approx \frac{\Delta I_C}{\Delta \beta}$$