MODULE 3
AMPLIFIERS

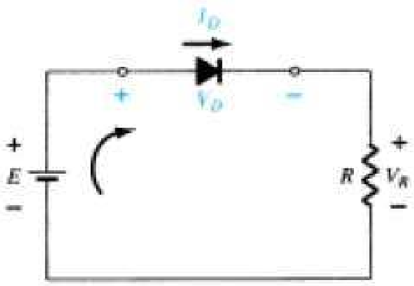
- **Introduction to transistor biasing,**
- **operating point,**
- **concept of load line,**
- **thermal stability,**
- **fixed bias, self bias, voltage divider bias.**

LOAD-LINE ANALYSIS

- **Applying Kirchhoff's** voltage law to the circuit

$$E - V_D - V_R = 0$$

$$\boxed{E = V_D + I_D R}$$



- **If we *set* V_D = 0 V**

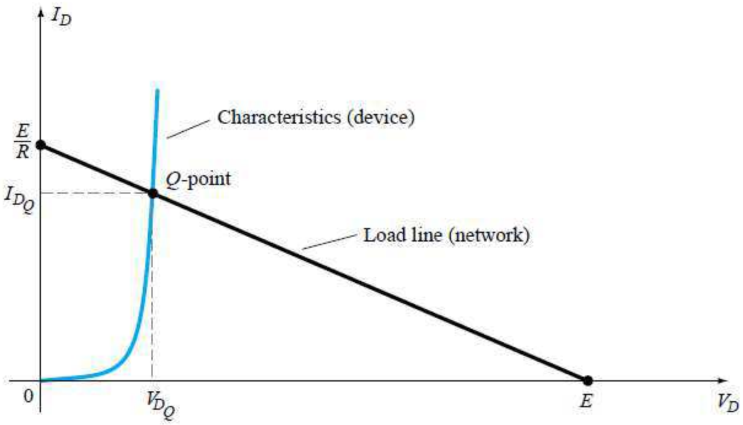
$$E = V_D + I_D R$$
$$= 0\text{ V} + I_D R$$
$$\boxed{I_D = \left.\frac{E}{R}\right|_{V_D = 0\text{ V}}}$$

- **If we *set* I_D = 0 A**

$$E = V_D + I_D R$$
$$= V_D + (0\text{ A})R$$
$$\boxed{V_D = E|_{I_D = 0\text{ A}}}$$

LOAD-LINE ANALYSIS

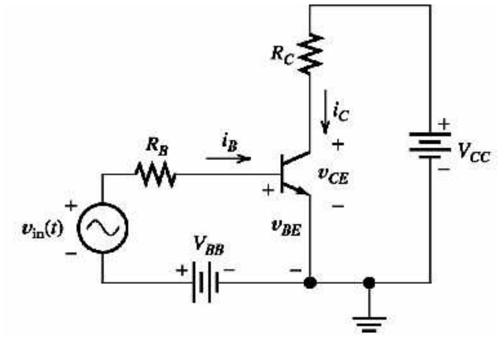
$$I_D = \frac{E}{R}\bigg|_{V_D=0\text{ V}}$$

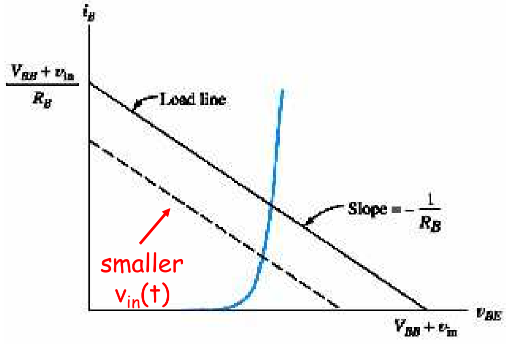


$$V_D = E|_{I_D=0\ A}$$

BJTs – LOAD LINE ANALYSIS

Common-Emitter Amplifier





(a) Input load line (shifts to dashed line for a smaller value of v_{in})

Applying KVL in Input loop

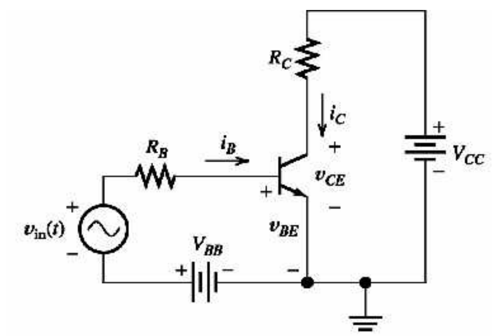
$$V_{BB} + v_{in}(t) = R_B i_B(t) + v_{BE}(t)$$

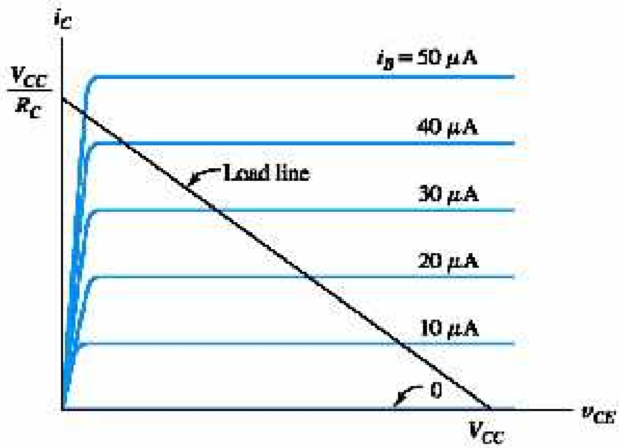
if $i_B=0$ $\quad v_{BE} = V_{BB} + v_{in}$

if $v_{BE}=0$ $\quad i_B = (V_{BB} + v_{in}) / R_B$

BJTs – LOAD LINE ANALYSIS

Common-Emitter Amplifier

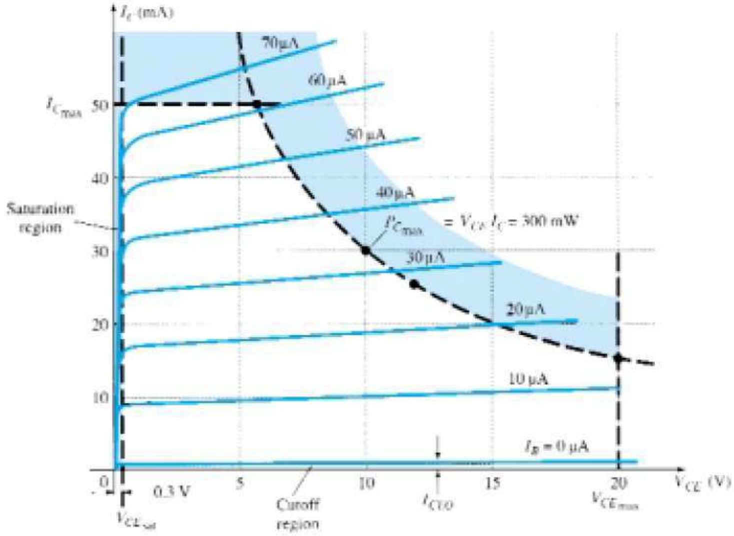




Applying KVL in Output loop

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

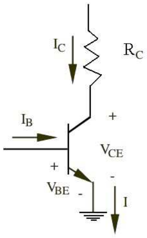
- Common Emitter configuration is the most common type of amplifier.
- The amplification happens in the active region where Base – Emitter junction is forward biased and Collector – Base junction is reverse biased.

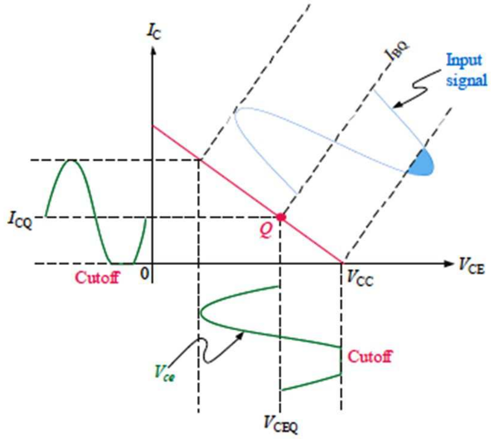


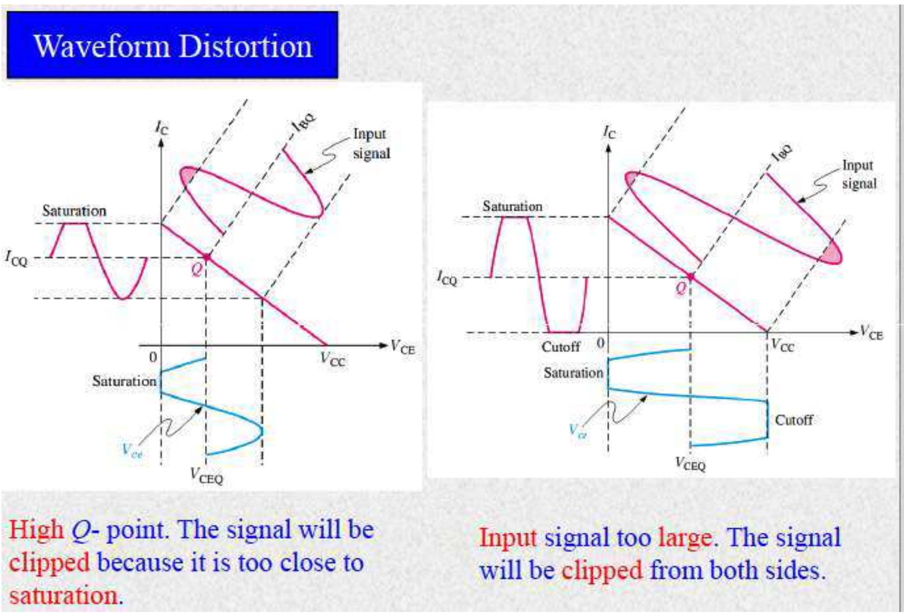
- The basic function of transistor is to do amplification.
- The weak signal is given to the base of the transistor and amplified output is obtained in the collector circuit.
- One important requirement during amplification is that only the magnitude of the signal should increase and there should be no change in signal shape.
- This increase in magnitude of the signal without any change in shape is known as *faithful amplification*.
- This is known achieved via transistor biasing.
- Wave form distortion will occur if the transistor is not properly biased.

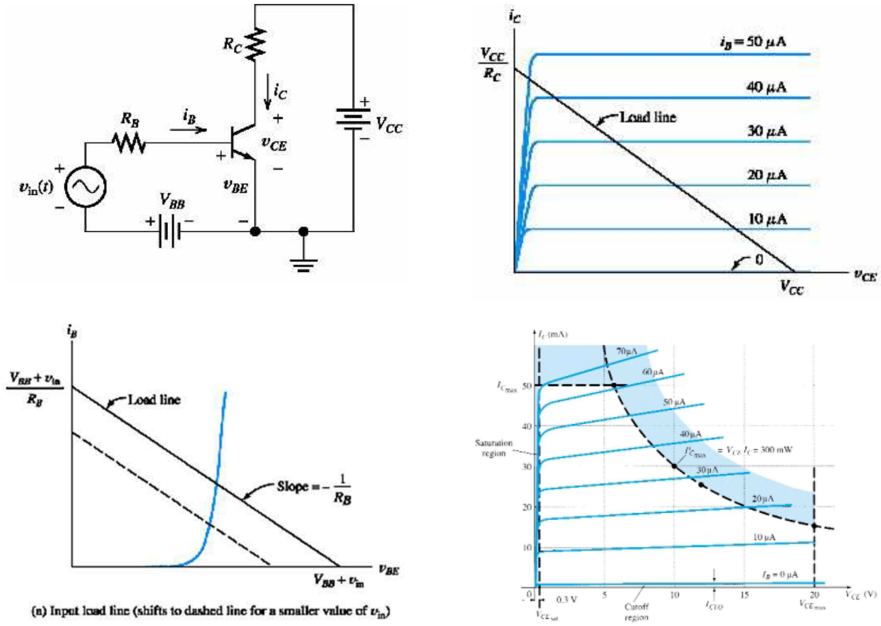
WAVEFORM DISTORTION

- 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.









(a) Input load line (shifts to dashed line for a smaller value of v_{in})

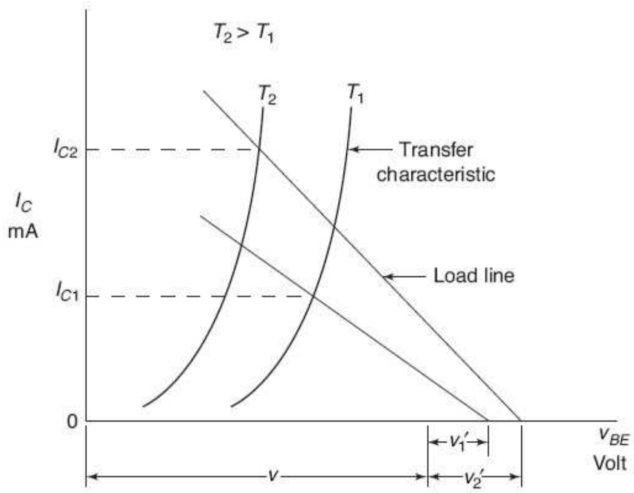
TRANSISTOR BIASING

- **The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.**
- **The basic purpose of transistor biasing is to keep the base-emitter junction properly forward biased and collector-base junction properly reverse biased during the application of signal.**
- **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.**

STABILISATION

- The collector current in a transistor changes rapidly when
- (i) the temperature changes,
- (ii) the transistor is replaced by another of the same type.
- This is due to the inherent variations of transistor parameters.
- When the temperature changes or the transistor is replaced, the operating point (i.e. zero signal I_C and V_{CE}) also changes.
- However, for faithful amplification, it is essential that operating point remains fixed.
- This necessitates to make the operating point independent of these variations.
- This is known as stabilisation.
- The process of making operating point independent of temperature changes or variations in transistor parameters is known as stabilisation.

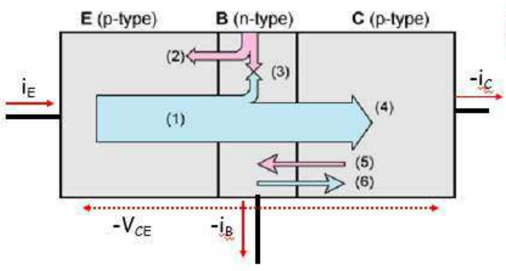
BIASING AND BIAS STABILITY



Variation of the collector current with temperature because of V_{BE}, I_{CO} and β

- Once stabilisation is done, the zero signal I_C and V_{CE} become independent of temperature variations or replacement of transistor i.e. the operating point is fixed.
- A good biasing circuit always ensures the stabilisation of operating point.
- <u>Need for stabilisation</u>
- Stabilisation of the operating point is necessary due to the following reasons :
  - (i) Temperature dependence of I_C
  - (ii) Individual variations
  - (iii) Thermal runaway

Current Flow in BJT



1. Injected h^+ current from E to B
2. e^- injected across the forward-biased EB junction (current from B to E)
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,

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

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

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

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

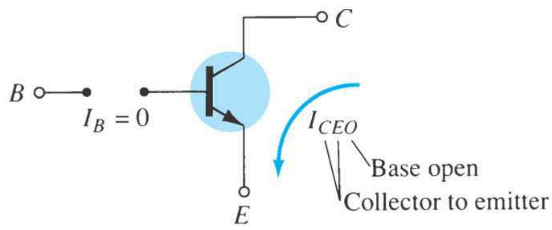
Now open the base lead which makes $I_B = 0$

So,

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

Emitter lead open

Base lead open



- (i) <u>Temperature dependence of I_C</u>
- 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) Thermal runaway**

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.**

- **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.**

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:

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

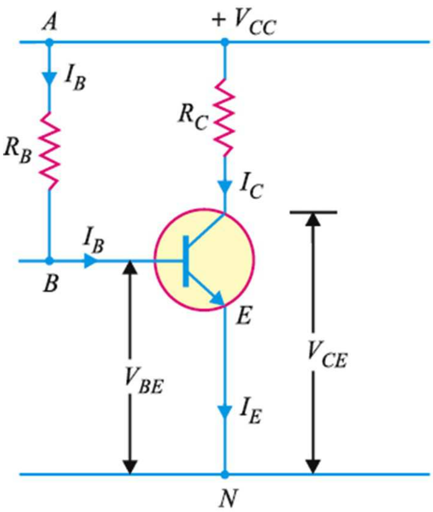
METHODS OF TRANSISTOR BIASING

- In the transistor amplifier circuits drawn so far, biasing was done with the aid of a battery V_{BB} which was separate from the battery V_{CC} used in the output circuit.
- However, in the interest of simplicity and economy, it is desirable that transistor circuit should have a single source of supply—the one in the output circuit (i.e. V_{CC}).
- The following are the most commonly used methods of obtaining transistor biasing from one source of supply (i.e. V_{CC}) :
- (i) Base resistor method (Fixed Bias)
- (ii) Biasing with collector-feedback resistor (Self Bias)
- (iii) Voltage-divider bias

- In all these methods, the same basic principle is employed i.e. required value of base current (and hence I_C) is obtained from V_{CC} in the zero signal conditions.
- The value of collector load R_C is selected keeping in view that V_{CE} should not fall below 0.5V for germanium transistors and 1V for silicon transistors.
- For example, if $\beta = 100$ and the zero signal collector current I_C is to be set at 1mA, then I_B is made equal to $I_C/\beta = 1/100 = 10$ µA.
- Thus, the biasing network should be so designed that a base current of 10 µA flows in the zero signal conditions.

BASE RESISTOR METHOD (FIXED BIAS)

- In this method, a high resistance R_B (several hundred kΩ) is connected between the base and +ve end of supply for npn transistor and between base and negative end of supply for pnp transistor.
- Here, the required zero signal base current is provided by V_{CC} and it flows through R_B.
- It is because now base is positive w.r.t. emitter i.e. base-emitter junction is forward biased.
- The required value of zero signal base current I_B (and hence $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B



- <u>Circuit analysis</u>.
- It is required to find the value of R_B so that required collector current flows in the zero signal conditions.
- Let I_C be the required zero signal collector current.

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

- Considering the closed circuit ABENA and applying Kirchhoff 's voltage law, we get,

$$V_{CC} = I_B R_B + V_{BE}$$

$$\text{or} \quad I_B R_B = V_{CC} - V_{BE}$$

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B}$$

- As V_{CC} and I_B are known and V_{BE} can be seen from the transistor manual, therefore, value of R_B can be readily found from above expression.
- Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error.
- It then follows from above expression that :

$$R_B = \frac{V_{CC}}{I_B}$$

- It may be noted that V_{CC} is a fixed known quantity and I_B is chosen at some suitable value.
- Hence, R_B can always be found directly, and for this reason, this method is sometimes called fixed-bias method.

- <u>Stability factor</u>
- We know

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

- In fixed-bias method of biasing, I_B is independent of I_C so that $dI_B/dI_C = 0$.
- Putting the value of $dI_B/dI_C = 0$ in the above expression, we have,

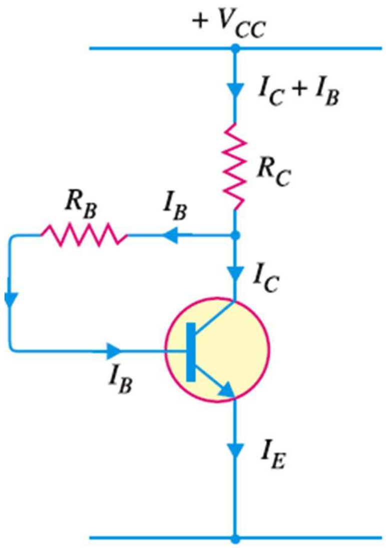
Stability factor, $S = \beta+1$

- Thus the stability factor in a fixed bias is $(\beta+1)$.
- This means that I_C changes $(\beta+1)$ times as much as any change in I_{CO}.
- For instance, if $\beta = 100$, then $S = 101$ which means that I_C increases 101 times faster than I_{CO}.
- Due to the large value of S in a fixed bias, it has poor thermal stability.

- **<u>Advantages</u> :**
- **(i) This biasing circuit is very simple as only one resistance R_B is required.**
- **(ii) Biasing conditions can easily be set and the calculations are simple.**
- **(iii) It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).**
- **<u>Disadvantages</u> :**
- **(i) This method provides poor stabilisation.**
- **It is because there is no means to stop a self increase in collector current due to temperature rise and individual variations.**
- **For example, if β increases due to transistor replacement, then I_C also increases by the same factor as I_B is constant.**
- **(ii) The stability factor is very high.**
- **Therefore, there are strong chances of thermal runaway.**
- **Due to these disadvantages, this method of biasing is rarely employed.**

BIASING WITH COLLECTOR FEEDBACK RESISTOR (SELF BIAS)

- **In this method, one end of R_B is connected to the base and the other end to the collector as shown in Figure.**
- **Here, the required zero signal base current is determined not by V_{CC} but by the collector base voltage V_{CB}.**
- **It is clear that V_{CB} forward biases the base-emitter junction and hence base current I_B flows through R_B.**
- **This causes the zero signal collector current to flow in the circuit.**



- **<u>Circuit analysis</u>.**
- **The required value of R_B needed to give the zero signal current I_C can be determined as follows.**
- **Referring to Figure,**

$$V_{CC} = {}^{*}I_C R_C + I_B R_B + V_{BE}$$

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B}$$

$$= \frac{V_{CC} - V_{BE} - \beta\, I_B R_C}{I_B} \quad (\because I_C = \beta\, I_B)$$

Alternatively. $V_{CE} = V_{BE} + V_{CB}$

or $V_{CB} = V_{CE} - V_{BE}$

$\therefore \quad R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B}$; where $I_B = \frac{I_C}{\beta}$

- **It can be shown mathematically that stability factor S for this method of biasing is less than (β + 1)**
- **i.e. Stability factor, S < (β + 1)**
- **Therefore, this method provides better thermal stability than the fixed bias.**

- **Note- It can be easily proved that Q-point values (I_C and V_{CE}) for this circuit are given by**

$$I_C = \frac{V_{CC} - V_{BE}}{R_B/\beta + R_C}$$

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

- **<u>Advantages</u>**
- **(i) It is a simple method as it requires only one resistance R_B.**
- **(ii) This circuit provides some stabilisation of the operating point as discussed below :**

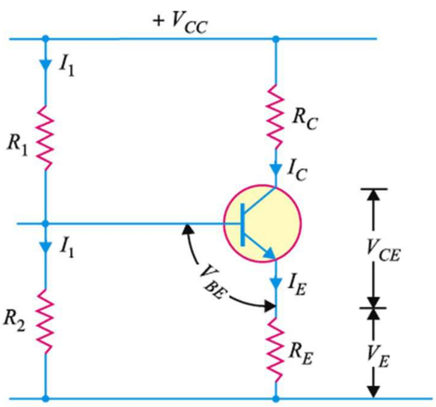
$$V_{CE} = V_{BE} + V_{CB}$$

- **Suppose the temperature increases.**
- **This will increase collector leakage current and hence the total collector current.**
- **But as soon as collector current increases, V_{CE} decreases due to greater drop across R_C.**
- **The result is that V_{CB} decreases i.e. lesser voltage is available across R_B.**
- **Hence the base current I_B decreases.**
- **The smaller I_B tends to decrease the collector current to original value.**

- **<u>Disadvantages</u>**
- **(i) The circuit does not provide good stabilisation because stability factor is fairly high, though it is lesser than that of fixed bias.**
- **Therefore, the operating point does change, although to lesser extent, due to temperature variations and other effects.**
- **(ii) This circuit provides a negative feedback which reduces the gain of the amplifier as explained hereafter.**
- **During the positive half-cycle of the signal, the collector current increases.**
- **The increased collector current would result in greater voltage drop across R_C.**
- **This will reduce the base current and hence collector current.**

VOLTAGE DIVIDER BIAS METHOD

- **This is the most widely used method of providing biasing and stabilisation to a transistor.**
- **In this method, two resistances R_1 and R_2 are connected across the supply voltage V_{CC} and provide biasing.**
- **The emitter resistance R_E provides stabilisation.**
- **The name "voltage divider" comes from the voltage divider formed by R_1 and R_2.**
- **The voltage drop across R_2 forward biases the base-emitter junction.**
- **This causes the base current and hence collector current flow in the zero signal conditions.**



- **Circuit analysis.**
- **Suppose that the current flowing through resistance R_1 is I_1.**
- **As base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1.**
- **(i) Collector current I_C :**

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

- **∴ Voltage across resistance R_2 is**

$$V_2 = \left(\frac{V_{CC}}{R_1 + R_2}\right) R_2$$

- **Applying Kirchhoff's voltage law to the base circuit**

$$\boldsymbol{V_2 = V_{BE} + V_E}$$

$$\textbf{or, } \boldsymbol{V_2 = V_{BE} + I_E R_E}$$

$$I_E = \frac{V_2 - V_{BE}}{R_E}$$

$$\text{Since } I_E \simeq I_C$$

$$I_C = \frac{V_2 - V_{BE}}{R_E}$$

- It is clear from expression above that I_C does not at all depend upon β.
- Though I_C depends upon V_{BE} but in practice V_2 >> V_{BE} so that I_C is practically independent of V_{BE}.
- Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilisation is ensured.
- It is due to this reason that potential divider bias has become universal method for providing transistor biasing.

- (ii) Collector-emitter voltage V_{CE}.
- Applying Kirchhoff 's voltage law to the collector side,

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

$$= I_C R_C + V_{CE} + I_C R_E$$

$$= I_C (R_C + R_E) + V_{CE}$$

$$\therefore \quad V_{CE} = V_{CC} - I_C (R_C + R_E)$$

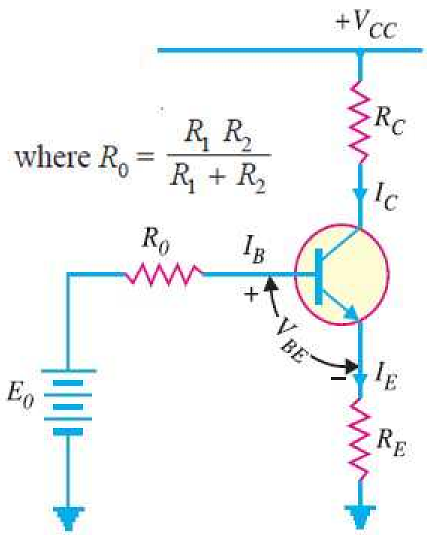
- <u>Stabilisation</u>
- In this circuit, excellent stabilisation is provided by R_E.
- Consideration of equation reveals this fact.

$$V_2 = V_{BE} + I_C R_E$$

- Suppose the collector current I_C increases due to rise in temperature.
- This will cause the voltage drop across emitter resistance R_E to increase.
- As voltage drop across R_2 (i.e. V_2) is *independent of I_C, therefore, V_{BE} decreases.
- This in turn causes I_B to decrease.
- The reduced value of I_B tends to restore I_C to the original value.

Stability Factor For Potential Divider Bias

- We can replace the potential divider circuit of potential divider bias by Thevenin's equivalent circuit.
- The resulting potential divider bias circuit is redrawn in Figure, in order to find the stability factor S for this biasing circuit.



- **Applying Kirchhoff's voltage law to the base circuit, we have,**

$$E_0 - I_B R_0 - V_{BE} - I_E R_E = 0$$

$$\text{Or, } E_0 = I_B R_0 + V_{BE} + (I_B + I_C) R_E$$

- **Considering V_{BE} to be constant and differentiating the above equation w.r.t. I_C, we have,**

$$0 = R_0 \frac{dI_B}{dI_C} + 0 + R_E \frac{dI_B}{dI_C} + R_E$$

$$\text{or} \qquad 0 = \frac{dI_B}{dI_C} (R_0 + R_E) + R_E$$

$$\therefore \qquad \frac{dI_B}{dI_C} = \frac{-R_E}{R_0 + R_E}$$

- **The general expression for stability factor is**

$$\text{Stability factor, } S = \frac{\beta + 1}{1 - \beta \dfrac{dI_B}{dI_C}}$$

- **Putting the value of dI_B/dI_C into the expression for S, we have,**

$$S = \frac{\beta + 1}{1 - \beta \dfrac{-R_E}{R_0 + R_E}} = \frac{\beta + 1}{1 + \left(\dfrac{\beta R_E}{R_0 + R_E} \right)}$$

$$= \frac{(\beta + 1)(R_0 + R_E)}{R_0 + R_E + \beta R_E} = \frac{(\beta + 1)(R_0 + R_E)}{R_0 + R_E (\beta + 1)}$$

$$S = (\beta + 1) \times \frac{R_0 + R_E}{R_E (\beta + 1) + R_0}$$

- **Dividing the numerator and denominator of R.H.S. of the above equation by R_E, we have,**

$$S = (\beta + 1) \times \frac{1 + R_0 / R_E}{\beta + 1 + R_0 / R_E}$$

- **This equation gives the formula for the stability factor S for the potential divider bias circuit.**
- **The following points may be noted carefully :**
- **(i) For greater thermal stability, the value of S should be small.**
- **This can be achieved by making R_0 /R_E small.**
- **If R_0 /R_E is made very small, then it can be neglected as compared to 1.**

$$\text{Stability factor} = (\beta + 1) \times \frac{1}{\beta + 1} = 1$$

- **This is the ideal value of S and leads to the maximum thermal stability.**

- **(ii) The ratio *R_0 /R_E can be made very small by decreasing R_0 and increasing R_E.**
- **Low value of R_0 can be obtained by making R_2 very small.**
- **But with low value of R_2, current drawn from V_{CC} will be large.**
- **This puts restriction on the choice of R_0.**
- **Increasing the value of R_E requires greater V_{CC} in order to maintain the same zero signal collector current.**
- **Due to these limitations, a compromise is made in the selection of the values of R_0 and R_E.**
- **Generally, these values are so selected that S≈10**

AMPLIFIERS

CLASSIFICATION OF AMPLIFIERS

- **An Amplifier circuit is one which strengthens the signal.**
- **Amplifiers are classified according to many considerations based on :-**
  1. **Number of stages**
  2. **Output**
  3. **Input signals**
  4. **Frequency range**
  5. **Biasing Conditions**
  6. **Coupling method**
  7. **Transistor Configuration**

1. BASED ON NUMBER OF STAGES

- **Depending upon the number of stages of Amplification, there are**
  1. **Single-stage amplifiers and**
  2. **Multi-stage amplifiers.**
- **Single-stage Amplifiers**
- **This has only one transistor circuit, which is a single stage amplification.**
- **Multi-stage Amplifiers**
- **This has multiple transistor circuit, which provides multi-stage amplification.**

2. BASED ON ITS OUTPUT

- **Depending upon the parameter that is amplified at the output, there are**
  1. **voltage amplifiers and**
  2. **power amplifiers.**
- **Voltage Amplifiers**
- **The amplifier circuit that increases the voltage level of the input signal, is called as Voltage amplifier.**
- **Power Amplifiers**
- **The amplifier circuit that increases the power level of the input signal, is called as Power amplifier.**

3. BASED ON THE INPUT SIGNALS

- **Depending upon the magnitude of the input signal applied, they can be categorized as**
  1. **Small signal and**
  2. **large signal amplifiers.**
- **<u>Small signal Amplifiers</u>**
- **When the input signal is so weak so as to produce small fluctuations in the collector current compared to its quiescent value, the amplifier is known as Small signal amplifier.**
- **<u>Large signal amplifiers</u>**
- **When the fluctuations in collector current are large i.e. beyond the linear portion of the characteristics, the amplifier is known as large signal amplifier.**

4. BASED ON FREQUENCY RANGE

- **Depending upon the frequency range of the signals being used, there are**

1. **Audio amplifiers and**
2. **Radio amplifiers**

- **<u>Audio Amplifiers</u>**
- **The amplifier circuit that amplifies the signals that lie in the audio frequency range i.e. from 20Hz to 20 KHz frequency range, is called as audio amplifier.**
- **<u>Radio Amplifiers</u>**
- **The amplifier circuit that amplifies the signals that lie in a very high frequency range, is called as Radio amplifier.**

5. BASED ON THE BIASING CONDITIONS

- **Depending upon their mode of operation, there are class A, class B and class C amplifiers.**
- **Class A amplifier − The biasing conditions in class A power amplifier are such that the collector current flows for the entire AC signal applied.**
- **Class B amplifier − The biasing conditions in class B power amplifier are such that the collector current flows for half-cycle of input AC signal applied.**
- **Class C amplifier − The biasing conditions in class C power amplifier are such that the collector current flows for less than half cycle of input AC signal applied.**
- **Class AB amplifier − The class AB power amplifier is one which is created by combining both class A and class B in order to have all the advantages of both the classes and to minimize the problems they have.**

5. BASED ON THE BIASING CONDITIONS

Amplifier Class	Description	Conduction Angle
Class-A	Full cycle 360^0 of Conduction	$\theta = 2\pi$
Class-B	Half cycle 180^0 of Conduction	$\theta = \pi$
Class-AB	Slightly more than 180^0 of conduction	$\pi < \theta < 2\pi$
Class-C	Slightly less than 180^0 of conduction	$\theta < \pi$

6. BASED ON THE COUPLING METHOD

- **Depending upon the method of coupling one stage to the other, there are**
  1. **RC coupled,**
  2. **Transformer coupled and**
  3. **direct coupled amplifier.**
- **<u>RC Coupled amplifier</u> − A Multi-stage amplifier circuit that is coupled to the next stage using resistor and capacitor (RC) combination can be called as a RC coupled amplifier.**
- **<u>Transformer Coupled amplifier</u> − A Multi-stage amplifier circuit that is coupled to the next stage, with the help of a transformer, can be called as a Transformer coupled amplifier.**
- **<u>Direct Coupled amplifier</u> − A Multi-stage amplifier circuit that is coupled to the next stage directly, can be called as a direct coupled amplifier.**

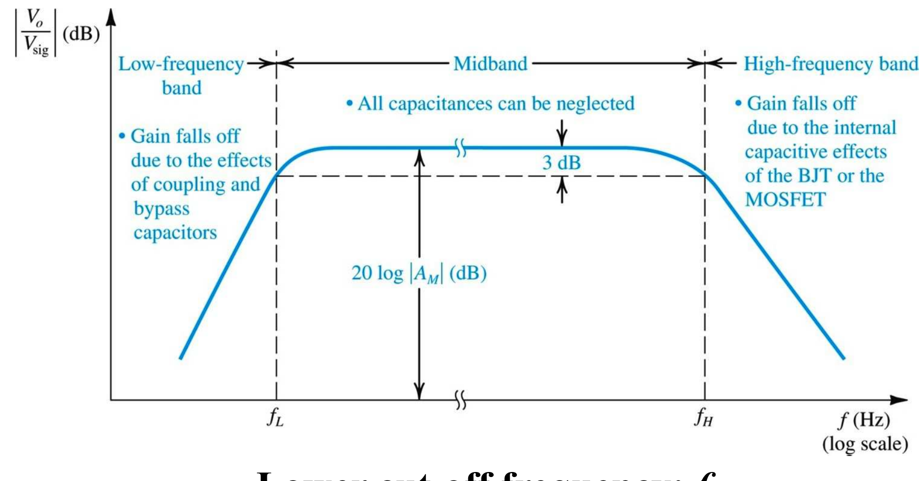
7. BASED ON THE TRANSISTOR CONFIGURATION

- **Depending upon the type of transistor configuration, there are (i) CE, (ii) CB and (iii) CC amplifiers.**
- **<u>CE amplifier</u>**
- **The amplifier circuit that is formed using a CE configured transistor combination is called as CE amplifier.**
- **<u>CB amplifier</u>**
- **The amplifier circuit that is formed using a CB configured transistor combination is called as CB amplifier.**
- **<u>CC amplifier</u>**
- **The amplifier circuit that is formed using a CC configured transistor combination is called as CC amplifier.**

MULTISTAGE AMPLIFIER

- The output from a single stage amplifier is usually insufficient to drive an output device.
- In other words, the gain of a single amplifier is inadequate for practical purposes.
- Consequently, additional amplification over two or three stages is necessary.
- To achieve this, the output of each amplifier stage is coupled in some way to the input of the next stage.
- The resulting system is referred to as multistage amplifier.
- A transistor circuit containing more than one stage of amplification is known as multistage transistor amplifier.
- It may be emphasised here that a practical amplifier is always a multistage amplifier.

FREQUENCY RESPONSE OF AMPLIFIERS



Lower cut-off frequency: f_L

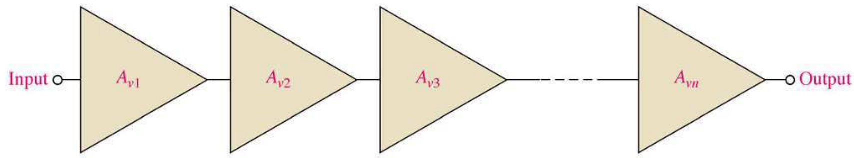
Upper cut-off frequency: f_H

Band-width: $BW = f_H - f_L$

FREQUENCY RESPONSE OF AMPLIFIERS

- <u>Midband</u>: The frequency range of interest for amplifiers
- Large capacitors can be treated as short circuit and small capacitors can be treated as open circuit
- Gain is constant and can be obtained by small-signal analysis
- <u>Low-frequency band</u>: Gain drops at frequencies lower than f_L
- Large capacitors can no longer be treated as short circuit
- The gain roll-off is mainly due to coupling and by-pass capacitors
- <u>High-frequency band</u>: Gain drops at frequencies higher than f_H
- Small capacitors can no longer treated as open circuit
- The gain roll-off is mainly due to parasitic capacitances of the MOSFETs and BJTs

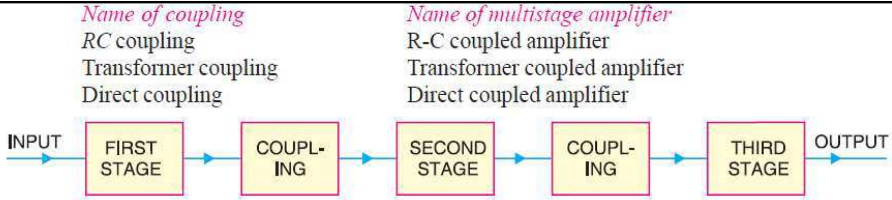
MULTISTAGE AMPLIFIERS



Two or more amplifiers can be connected to increase the gain of an ac signal.

The overall gain can be calculated by simply multiplying each gain together.

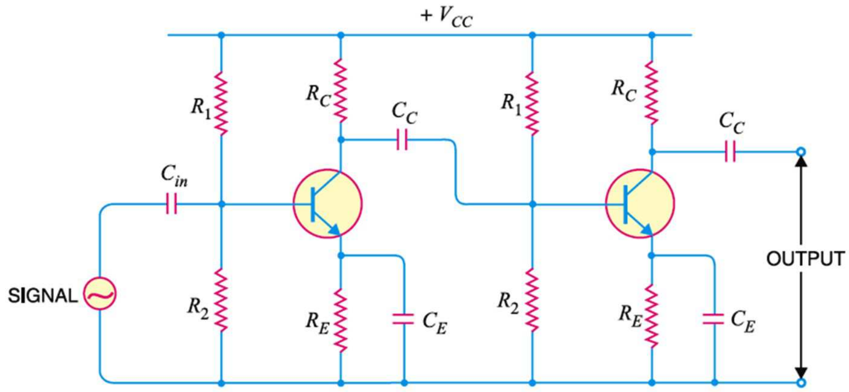
$$A'_v = A_{v1}A_{v2}A_{v3} \ldots\ldots$$



- **(i) In RC coupling, a capacitor is used as the coupling device.**
  - **The capacitor connects the output of one stage to the input of the next stage in order to pass the a.c. signal on while blocking the d.c. bias voltages.**
- **(ii) In transformer coupling, transformer is used as the coupling device.**
  - **The transformer coupling provides the same two functions (viz. to pass the signal on and blocking d.c.) but permits in addition impedance matching.**
- **(iii) In direct coupling or d.c. coupling, the individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for d.c. isolation.**

RC COUPLED TRANSISTOR AMPLIFIER

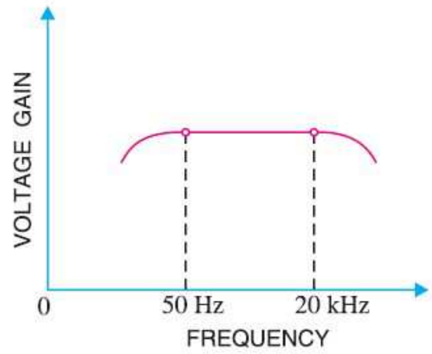
- **This is the most popular type of coupling because it is cheap and provides excellent fidelity over a wide range of frequency.**
- **It is usually employed for voltage amplification.**
- **Figure below shows two stages of an RC coupled amplifier.**



- A coupling capacitor C_C is used to connect the output of first stage to the base (i.e. input) of the second stage and so on.
- As the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called resistance - capacitance coupled amplifiers.
- The resistances R_1, R_2 and R_E form the biasing and stabilisation network.
- The emitter bypass capacitor offers low reactance path to the signal.
- Without it, the voltage gain of each stage would be lost.
- The coupling capacitor C_C transmits a.c. signal but blocks d.c.
- This prevents d.c. interference between various stages and the shifting of operating point.

- <u>Operation</u>
- When a.c. signal is applied to the base of the first transistor, it appears in the amplified form across its collector load R_C.
- The amplified signal developed across R_C is given to base of next stage through coupling capacitor C_C.
- The second stage does further amplification of the signal.
- In this way, the cascaded (one after another) stages amplify the signal and the overall gain is considerably increased.
- It may be mentioned here that total gain is less than the product of the gains of individual stages.

- **<u>Frequency response</u>**
- **Figure below shows the frequency response of a typical RC coupled amplifier.**



- **It is clear that voltage gain drops off at low and high frequencies whereas it is uniform over mid-frequency range.**

- **This behaviour of the amplifier is briefly explained below :**
- **(i) At low frequencies, the reactance of coupling capacitor C_C is quite high and hence very small part of signal will pass from one stage to the next stage.**
- **Moreover, C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies.**
- **These two factors cause a falling of voltage gain at low frequencies.**
- **(ii) At high frequencies, the reactance of C_C is very small and it behaves as a short circuit.**
- **This increases the loading effect of next stage and serves to reduce the voltage gain.**
- **Moreover, at high frequency, capacitive reactance of base-emitter junction is low which increases the base current.**

- **This reduces the current amplification factor β.**
- **Due to these two reasons, the voltage gain drops off at high frequency.**
- **(iii) At mid-frequencies, the voltage gain of the amplifier is constant.**
- **The effect of coupling capacitor in this frequency range is such so as to maintain a uniform voltage gain.**
- **Thus, as the frequency increases in this range, reactance of C_C decreases which tends to increase the gain (as large part of signal passes easily from one stage to other).**
- **However, at the same time, lower reactance means higher loading of first stage and hence lower gain.**
- **These two factors almost cancel each other, resulting in a uniform gain at mid-frequency.**

- **<u>Advantages</u>**
- **(i) It has excellent frequency response.**
  - **The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.**
- **(ii) It has lower cost since it employs resistors and capacitors which are cheap.**
- **(iii) The circuit is very compact as the modern resistors and capacitors are small and extremely light.**
- **<u>Disadvantages</u>**
- **(i) The RC coupled amplifiers have low voltage and power gain.**
  - **It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.**
- **(ii) They have the tendency to become noisy with age, particularly in moist climates.**

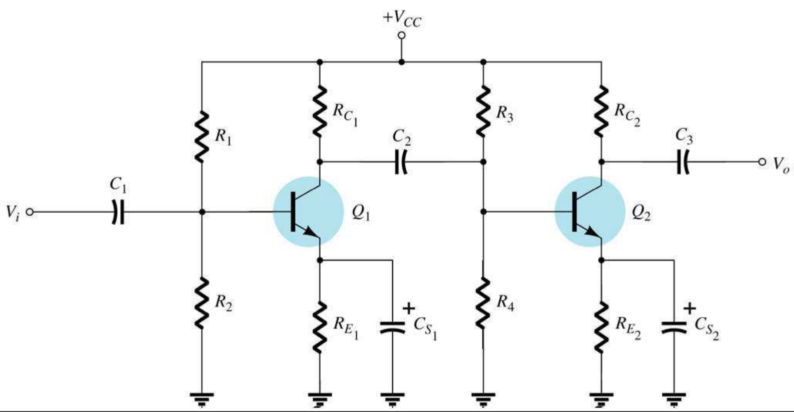
- (iii) Impedance matching is poor.
- It is because the output impedance of RC coupled amplifier is several hundred ohms whereas the input impedance of a speaker is only a few ohms.
- Hence, little power will be transferred to the speaker.
- <u>Applications</u>
- The RC coupled amplifiers have excellent audio fidelity over a wide range of frequency.
- Therefore, they are widely used as voltage amplifiers e.g. in the initial stages of public address system.
- If other type of coupling (e.g. transformer coupling) is employed in the initial stages, this results in frequency distortion which may be amplified in next stages.
- However, because of poor impedance matching, RC coupling is rarely used in the final stages.

CASCADING - SUMMARY

-The most widely used method

-The signal developed across the collector resistor of each stage is coupled into the base of the next stage

-The overall gain = product of the individual gain

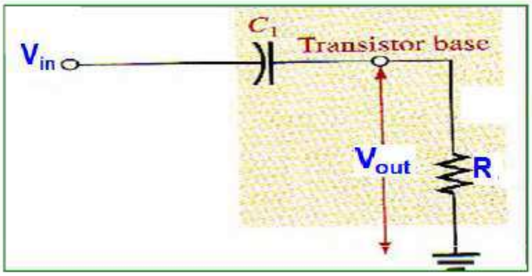


EFFECT OF CASCADING ON BANDWIDTH

- For a second transistor stage connected directly to the output of a first stage, there will be a significant change in the overall frequency response.
- In the high-frequency region, the output capacitance C_o must now include the wiring capacitance, parasitic capacitance e.t.c of the following stage.
- Further, there will be additional low-frequency cutoff levels due to the second stage that will further reduce the overall gain of the system in this region.
- For each additional stage, the upper cutoff frequency will be determined primarily by that stage having the lowest cutoff frequency.
- The low-frequency cutoff is primarily determined by that stage having the highest low-frequency cutoff frequency.

Multistage Amplifiers: Frequency Response

$$V_o = \left(\frac{R}{R - jX_c}\right)V_{in}$$



$$A_v = \frac{V_{out}}{V_{in}} = \frac{R}{R - j(1/\omega C)}$$

$$A_v = \frac{1}{1 - j(1/2\pi fCR)}$$

$$\boxed{A_v = \frac{1}{1 - j(f_1/f)} \quad f_1 = 1/2\pi RC}$$

$$\boxed{A_v = \frac{1}{\sqrt{1 + (f_1/f)^2}} \angle \tan^{-1}(f_1/f)}$$

Multistage Amplifiers: Low cut off Frequency

If n identical stages are connected together then overall voltage gain at lower frequency is given by:

$$A_{v\text{-low}} = A_{v1\text{-low}} \times A_{v2\text{-low}} \times A_{v3\text{-low}} \cdots\cdots\cdots \times A_{vn\text{-low}} = (A_{v\text{-low}})^n$$

where *n* is the number of cascaded stages. Since

$$A_{v1\text{-low}} = A_{v2\text{-low}} \cdots\cdots = A_{vn\text{-low}}$$

$$\left(\frac{A_{v-low}}{A_{v-mid}}\right)_{overall} = \left(\frac{A_{v-low}}{A_{v-mid}}\right)^n = \frac{1}{(1 - j(f_1/f))^n}$$

For lower cutoff frequency : $A_{v\text{-low}} / A_{v\text{-mid}})_{overall} = 1/\sqrt{2}$

$$\frac{1}{\sqrt{[1+(f_1/f_{c-low})^2]^n}} = \frac{1}{\sqrt{2}}$$

$$\boxed{f_{c-low} = \frac{f_1}{\sqrt{2^{\frac{1}{n}} - 1}}}$$

7

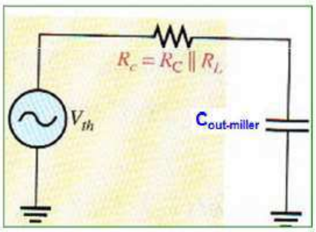
Multistage Amplifiers: High Cutoff Frequency

$$V_o = \left(\frac{-jX_c}{R - jX_c}\right)V_{in} \qquad A_v = \frac{V_{out}}{V_{in}} = \frac{1}{1 + j(R\omega C)}$$

$$\boxed{A_v = \frac{1}{1 + j(2\pi fCR)} = \frac{1}{1 + j(f/f_2)}} \qquad \boxed{A_v = \frac{1}{\sqrt{1 + (f/f_2)^2}} \angle \tan^{-1}(f/f_2)}$$

where $f_2 = 1/2\pi RC$

$$\left(\frac{A_{v-high}}{A_{v-mid}}\right)_{overall} = \left(\frac{A_{v-high}}{A_{v-mid}}\right)^n = \frac{1}{(1 + j(f/f_2))^n}$$



For cutoff frequency : $A_{v\text{-high}} / A_{v\text{-mid}})_{overall} = 1/\sqrt{2}$

$$\frac{1}{\sqrt{[1+(f_{c-high}/f_2)^2]^n}} = \frac{1}{\sqrt{2}}$$

$$\boxed{f_{c-high} = f_2\sqrt{2^{\frac{1}{n}} - 1}}$$

8

Multistage Amplifiers: Frequency Response

The cutoff frequencies for cascaded amplifiers with identical values of f_{c1} and f_{c2} are found using

$$f_{c-low} = \frac{f_{c1}}{\sqrt{2^{\frac{1}{n}} - 1}}$$

$$f_{c-high} = f_{c2}\sqrt{2^{\frac{1}{n}} - 1}$$

$$BW_{overall} = f_{c-high} - f_{c-low}$$

where *n* is the number of cascaded stages.

When Each stage has a different lower & upper critical frequency

- When the lower critical frequency, f_{cL} , of each amplifier stage is different, the dominant lower critical frequency, f'_{cL} equals the critical frequency of the stage with the highest f_{cL}.
- When the upper critical frequency f_{cu}, of each amplifier stage is different, the dominant upper critical frequency f'_{cu}, equals the critical frequency of the stage with the lowest f_{cu}

EFFECT OF CASCADING ON BANDWIDTH

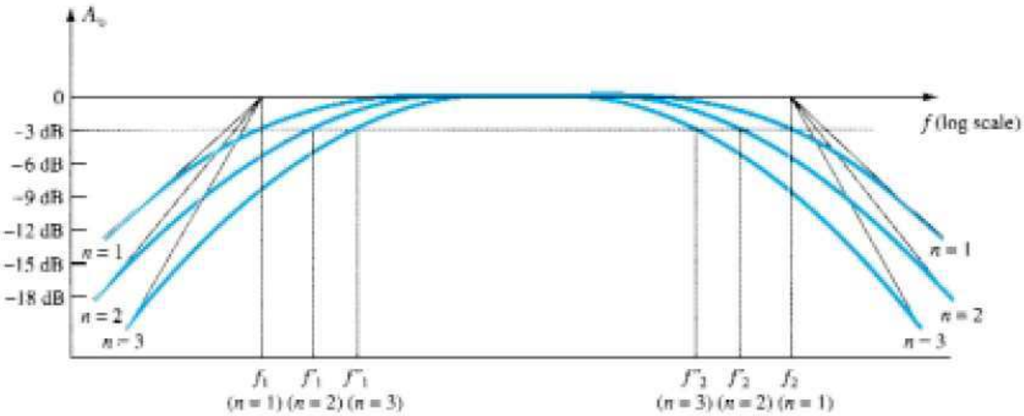


Figure 11.57 Effect of an increased number of stages on the cutoff frequencies and the bandwidth.

CONCEPT OF FEEDBACK

- A feedback system is one in which a part or fraction of the output is combined with the input.
- Feedback system use the output information to modify the input signal to achieve the desired result.
- Feedback systems are of two types:
  - i. Negative Feedback System
  - ii. Positive Feedback System

NEGATIVE FEEDBACK

- In negative feedback systems, feedback tends to reduce the input.
- This kind of feedback is called degenerative feedback.
- Negative feedback reduces the amplifier gain.
- But it has many advantages such as
  - Gain stability
  - Reduction in distortion and noise
  - Increase in bandwidth
  - Increase in input impedance
  - Decrease in output impedance

etc

POSITIVE FEEDBACK

- In the positive feedback systems, the feedback tends to increase the input.
- This form of feedback is called regenerative feedback.
- Since positive feedback causes excessive distortion and instability, it is seldom used in amplifiers.
- However, it increases the strength of the original signal and hence it is employed in oscillator circuits.

TYPES OF FEEDBACK

- There are four basic ways of connecting the feedback signal.
- Both voltage and current can be fed back to the input either in series or parallel.
- Specifically, there can be:
    - 1. Voltage-series feedback
    - 2. Voltage-shunt feedback
    - 3. Current-series feedback
    - 4. Current-shunt feedback

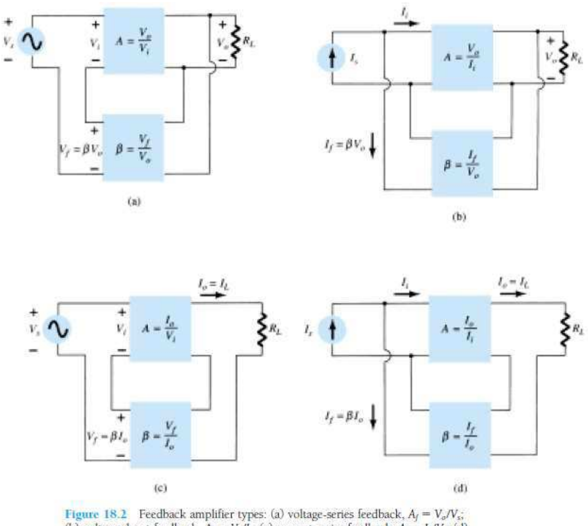
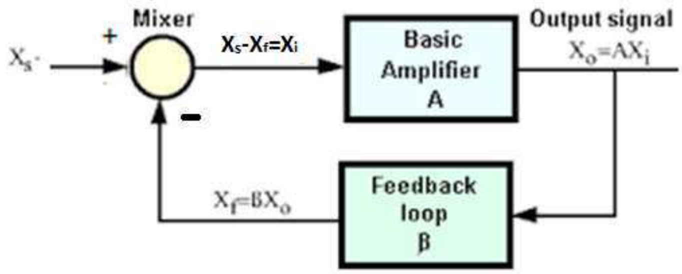


Figure 18.2 Feedback amplifier types: (a) voltage-series feedback, $A_f = V_o/V_s$; (b) voltage-shunt feedback, $A_f = V_o/I_s$; (c) current-series feedback, $A_f = I_o/V_s$; (d) current-shunt feedback, $A_f = I_o/I_s$.

- In the list above, voltage refers to connecting the output voltage as input to the feedback network; current refers to tapping off some output current through the feedback network.
- Series refers to connecting the feedback signal in series with the input signal voltage; shunt refers to connecting the feedback signal in shunt (parallel) with an input current source.
- Series feedback connections tend to increase the input resistance, while shunt feedback connections tend to decrease the input resistance.
- Voltage feedback tends to decrease the output impedance, while current feedback tends to increase the output impedance.
- Typically, higher input and lower output impedances are desired for most cascade amplifiers.
- Both of these are provided using the voltage-series feedback connection.
- We shall therefore concentrate first on this amplifier connection.

FEEDBACK IN AMPLIFIERS

- A feedback amplifier essentially consists of two parts, an amplifier and a feedback network as shown in the figure below.



- The function of feedback network is to return a fraction of the output energy (voltage or current) to the input of the amplifier.

- For an amplifier without feedback, the gain equals the ratio of output to input of the amplifier.

$$\text{i.e Gain } A = V_o / V_i$$

- A is called the open – loop gain, i.e the gain of the amplifier without feedback.
- Here x_s represents the signal which may be voltage or current applied to the whole system.
- The output of the amplifier x_0 is applied to a feedback network which has a gain β.
- Thus the feedback network produces a signal $x_f = \beta x_0$ which is subtracted from the input source signal, x_s.
- The resulting signal, x_i, also called the error signal, is the input to the amplifier which in turn produces the output signal $V_o = Ax_i$

- Thus the actual input to the amplifier becomes
- $x_i = x_s - x_f = x_s - \beta x_o$ in case of negative feedback and
- $x_i = x_s + x_f = x_s + \beta x_o$ in case of positive feedback.
- Consider a negative feedback case.
- The actual input to the amplifier,

$$x_i = x_s - \beta x_o$$

- We have amplifier gain,

$$A = x_o / x_i$$

$$Ax_i = x_o$$

Then, on substitution

$$A(x_s - \beta x_o) = x_o$$

- **Or,**

$$\frac{x_o}{x_s} = \frac{A}{1+A\beta}$$

- **$\frac{x_o}{x_s}$ is the gain of the amplifier with feedback which is usually given the symbol G.**
- **Therefore the gain with negative feedback is expressed as,**

$$G = \frac{x_o}{x_s} = \frac{A}{1+A\beta}$$

- **This expression for the gain is also known as the transfer function of a feedback system.**
- **By doing similar analysis, gain with <u>positive feedback</u> is obtained as**

$$G = \frac{A}{1-A\beta}$$

- **Here**
  - **G is called the closed loop gain (the gain of the circuit with feedback present)**
  - **A is the open loop gain (the gain without feedback) and**
  - **Aβ represents the loop gain.**
- **The overall characteristics of the system depend on the values of A and β or more directly on the item $1 + A\beta$.**
- **Let us consider some possible values for A, β and the term $1 + A\beta$ to see how they affect the overall gain G.**
- **(i) <u>No feedback, i.e, β = 0</u>**
- **We have, gain of the negative feedback system $G = \frac{A}{1+A\beta}$**
- **As seen earlier, if there is no feedback, the overall gain will be equal to the open – loop gain A**

- (ii) <u>The loop gain Aβ is negative</u>
- If either A or β is negative (but not both), the product Aβ will be negative.
- If the term <u>1+Aβ is less than 1</u>, G is greater than A.
- In this case, the gain of the circuit will be increased by the feedback.
- When <u>Aβ = -1</u>, we get

$$G = \frac{A}{1+A\beta} = \frac{A}{1-1} = \infty$$

- As the gain of the circuit is infinity, it can produce an output even in the absence of an input and this characteristic makes it useful as an oscillator.

- (iii) <u>The loop gain Aβ is positive</u>
- If A and β are either positive or both negative, the product Aβ will be negative.
- Thus the term 1+Aβ must be positive and <u>greater than 1</u>, G must be less than A.
- So the gain of the circuit will be reduced with feedback.
- This is therefore a negative feedback.
- If the loop gain <u>Aβ is large compared with unity</u>, the expression for overall gain,

$$G = \frac{A}{1+A\beta}$$

- This expression can be simplified as

$$G = \frac{A}{A\beta} = \frac{1}{\beta} \text{ if } A\beta >> 1$$

- Thus the overall gain becomes independent of the open loop gain A and depends only on feedback network.
- From the above analysis, it is clear that since the feedback signal is being subtracted from the input signal, a positive loop gain will produce negative feedback and a negative loop gain will produce positive feedback.

- **STABILIZATION OF GAIN WITH NEGATIVE FEEDBACK**
- The gain of an amplifier can be stabilized with negative feedback.
- Let the gain of an amplifier without feedback, i.e., open loop gain be A, with feedback the gain becomes

$$G = \frac{A}{1+A\beta}$$

- Here, note that the gain is reduced by a factor of $1 + A\beta$
- If $A\beta$ >>1, then the expression for closed loop gain can be approximated as

$$G = \frac{A}{1+A\beta} = \frac{1}{\beta}$$

- Thus the closed loop gain G depends only on the gain of the feedback network, β which is determined by passive components such as resistors.
- Thus the gain of the amplifier is stabilized with feedback.

ADVANTAGES OF NEGATIVE FEEDBACK

- **In addition to gain – stability, there are numerous advantages for negative feedback.**
- **Some of the advantages are:**
  1. **Increased bandwidth**
  2. **Better stabilized voltage gain**
  3. **Increased input impedance**
  4. **Reduced output impedance**
  5. **Reduced non – linear distortion**
  6. **Reduced noise.**

REDUCTION IN FREQUENCY DISTORTION

- **For a negative-feedback amplifier having $\beta A >> 1$, the gain with feedback is $A_f \approx 1/\beta$.**
- **It follows from this that if the feedback network is purely resistive, the gain with feedback is not dependent on frequency even though the basic amplifier gain is frequency dependent.**
- **Practically, the frequency distortion arising because of varying amplifier gain with frequency is considerably reduced in a negative-voltage feedback amplifier circuit.**

REDUCTION IN NOISE AND NONLINEAR DISTORTION

- Signal feedback tends to hold down the amount of noise signal (such as power-supply hum) and nonlinear distortion.
- The factor $(1+\beta A)$ reduces both input noise and resulting nonlinear distortion for considerable improvement.
- However, it should be noted that there is a reduction in overall gain (the price required for the improvement in circuit performance).
- If additional stages are used to bring the overall gain up to the level without feedback, it should be noted that the extra stage(s) might introduce as much noise back into the system as that reduced by the feedback amplifier.
- This problem can be somewhat alleviated by readjusting the gain of the feedback-amplifier circuit to obtain higher gain while also providing reduced noise signal.

EFFECT OF NEGATIVE FEEDBACK ON GAIN AND BANDWIDTH

- The overall gain with negative feedback is shown to be

$$A_f = \frac{A}{1+\beta A} \cong \frac{A}{\beta A} = \frac{1}{\beta} \qquad \text{for } \beta A \gg 1$$

- As long as $\beta A >> 1$, the overall gain is approximately $1/\beta$.
- We should realize that for a practical amplifier (for single low- and high-frequency breakpoints) the open-loop gain drops off at high frequencies due to the active device and circuit capacitances.
- Gain may also drop off at low frequencies for capacitively coupled amplifier stages.
- Once the open-loop gain A drops low enough and the factor A is no longer much larger than 1, the conclusion that $A_f \approx 1/\beta$ no longer holds true.

- **Figure below shows that the amplifier with negative feedback has more bandwidth (B_f) than the amplifier without feedback (B).**
- **The feedback amplifier has a higher upper 3-dB frequency and smaller lower 3-dB frequency.**

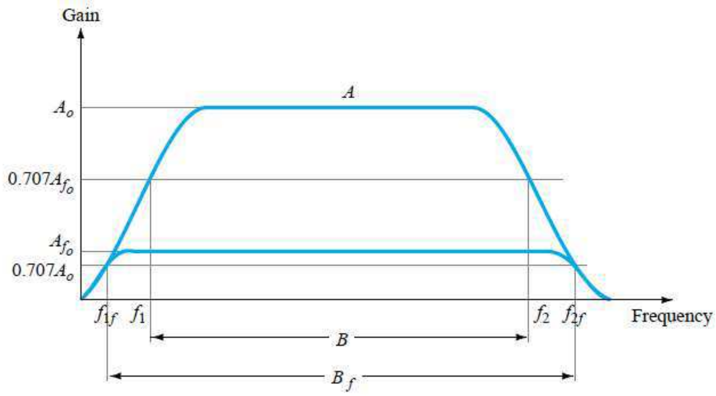


Figure 18.6 Effect of negative feedback on gain and bandwidth.

- **It is interesting to note that the use of feedback, while resulting in a lowering of voltage gain, has provided an increase in *B* and in the upper 3-dB frequency particularly.**
- **In fact, the product of gain and frequency remains the same so that the gain– bandwidth product of the basic amplifier is the same value for the feedback amplifier.**
- **However, since the feedback amplifier has lower gain, the net operation was to *trade* gain for bandwidth (we use bandwidth for the upper 3-dB frequency since typically $f_2 >> f_1$).**

Common Source MOSFET Amplifier

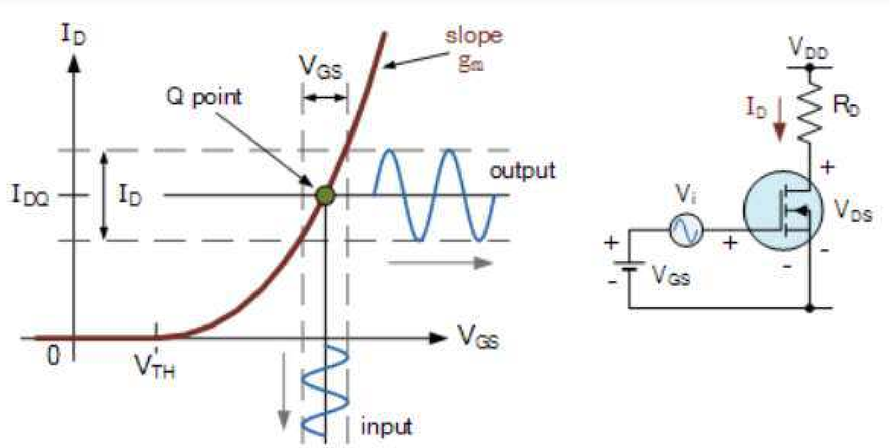
MOSFET AMPLIFIER

- **Metal Oxide Semiconductor Field Effect Transistor, or MOSFET for short, is an excellent choice for small signal linear amplifiers as their input impedance is extremely high making them easy to bias.**
- **But for a mosfet to produce linear amplification, it has to operate in its saturation region, unlike the Bipolar Junction Transistor.**
- **But just like the BJT, it too needs to be biased around a centrally fixed Q-point.**
- **Enhancement MOSFETS, or eMOSFETS, can be classed as normally-off (non-conducting) devices, that is they only conduct when a suitable gate-to-source positive voltage is applied, unlike Depletion type mosfets which are normally-on devices conducting when the gate voltage is zero.**

DC BIASING THE MOSFET

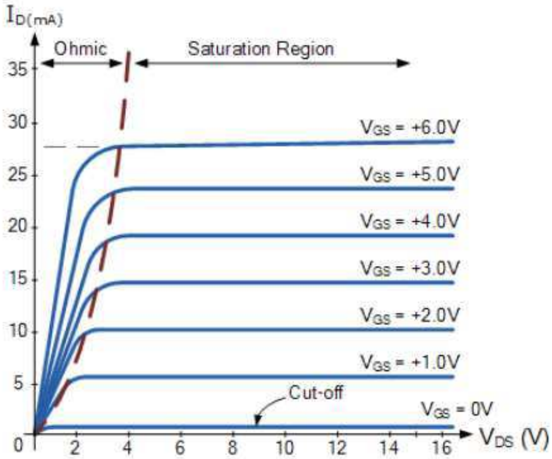
- The universal voltage divider biasing circuit is a popular biasing technique used to establish a desired DC operating condition of bipolar transistor amplifiers as well as mosfet amplifiers.
- The advantage of the voltage divider biasing network is that the MOSFET, or indeed a bipolar transistor, can be biased from a single DC supply.
- A mosfet device has three different regions of operation.
- These regions are called the: *Ohmic/Triode region*, *Saturation/Linear region* and *Pinch-off point*.
- For a mosfet to operate as a linear amplifier, we need to establish a well-defined quiescent operating point, or Q-point, so it must be biased to operate in its saturation region.

- The Q-point for the mosfet is represented by the DC values, I_D and V_{GS} that position the operating point centrally on the mosfets output characteristics curve.



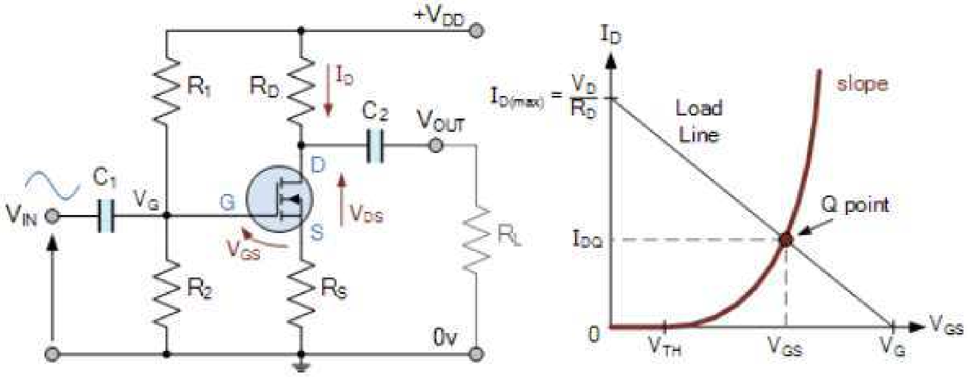
- The common-source NMOS circuit above shows that the sinusoidal input voltage, V_i is in series with a DC source.
- This DC gate voltage will be set by the bias circuit.
- Then the total gate-source voltage will be the sum of V_{GS} and V_i.
- The DC characteristics and therefore Q-point (quiescent point) are all functions of gate voltage V_{GS}, supply voltage V_{DD} and load resistance R_D.
- As the instantaneous value of V_{GS} increases, the bias point moves up the curve as shown allowing a larger drain current to flow as V_{DS} decreases.
- Likewise, as the instantaneous value of V_{GS} decreases (during the negative half of the input sine wave), the bias point moves down the curve and a smaller V_{GS} results in a smaller drain current and increased V_{DS}.
- Then in order to establish a large output swing we must bias the transistor well above threshold level to ensure that the transistor stays in saturation over the full sinusoidal input cycle.

N-TYPE EMOSFET CHARACTERISTIC CURVES



- Note that a p-channel eMOSFET device would have a very similar set of drain current characteristics curves but the polarity of the gate voltage would be reversed.

BASIC COMMON SOURCE MOSFET AMPLIFIER



- This simple enhancement-mode common source mosfet amplifier configuration uses a single supply at the drain and generates the required gate voltage, V_G using a resistor divider.
- We remember that for a MOSFET, no current flows into the gate terminal and from this we can make the following basic assumptions about the MOSFET amplifiers DC operating conditions.

$$V_{DD} = I_D R_D + V_{DS} + I_D R_S$$
$$= I_D (R_D + R_S) + V_{DS}$$

$$\therefore R_D + R_S = \frac{V_{DD} - V_{DS}}{I_D}$$

Then from this we can say that:

$$R_D = \frac{V_{DD} - V_D}{I_D} \quad \text{and} \quad R_S = \frac{V_S}{I_D}$$

- The MOSFETs gate-to-source voltage, V_{GS} is given as:

$$V_{GS} = V_G - I_S R_S$$

- As we have seen above, for proper operation of the mosfet, this gate-source voltage must be greater than the threshold voltage of the mosfet, that is $V_{GS} > V_{TH}$.
- Since $I_S = I_D$, the gate voltage, V_G is therefore equal too:

$$V_{GS} = V_G - I_D R_S$$

$$\therefore V_G = V_{GS} + I_D R_S$$

$$\text{or } V_G = V_{GS} + V_S$$

Where,

$$V_G = V_{DD}\left(\frac{R_2}{R_1 + R_2}\right)$$