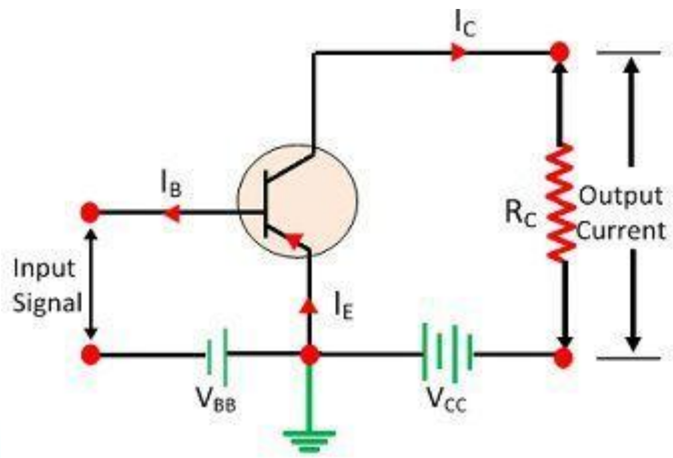
TRANSISTOR AMPLIFIER AND OSCILLATORS

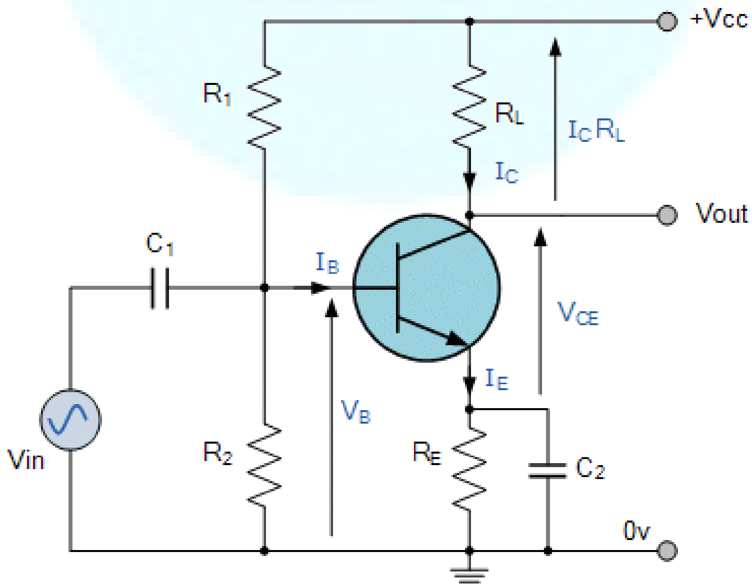
Introduction to Amplifiers

Amplification means enlargement of a weak signal by an electronic circuit without any distortion in the signal. The electronic circuit or device which amplifies the signal is known as Amplifier.

After proper DC biasing AC signal to be amplified is fed to the input of a transistor which is amplified by the transistor as per its configuration. Now the transistor works as an amplifier.



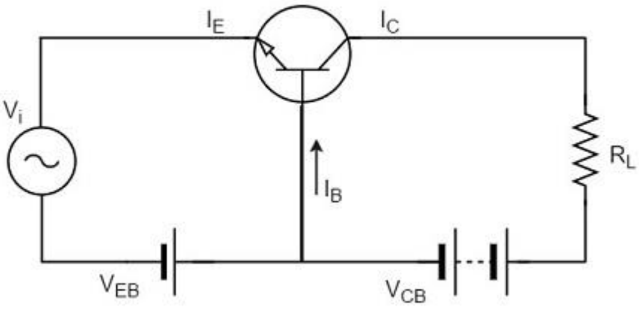
Circuit diagram of DC biasing for a transistor to work in active region.



The circuit diagram of a transistor amplifier which amplifies weak input signal

Transistor Amplifier

A transistor acts as an amplifier by raising the strength of a weak signal. The DC bias voltage applied to the emitter base junction, makes it remain in forward biased condition. This forward bias is maintained regardless of the polarity of the signal. The below figure shows how a transistor looks like when connected as an amplifier.



The low resistance in input circuit, lets any small change in input signal to result in an appreciable change in the output. The emitter current caused by the input signal contributes the collector current, which when flows through the load resistor R_L, results in a large voltage drop across it. Thus, a small input voltage results in a large output voltage, which shows that the transistor works as an amplifier.

Example

Let there be a change of 0.1v in the input voltage being applied, which further produces a change of 1mA in the emitter current. This emitter current will obviously produce a change in collector current, which would also be 1mA.

A load resistance of 5kΩ placed in the collector would produce a voltage of

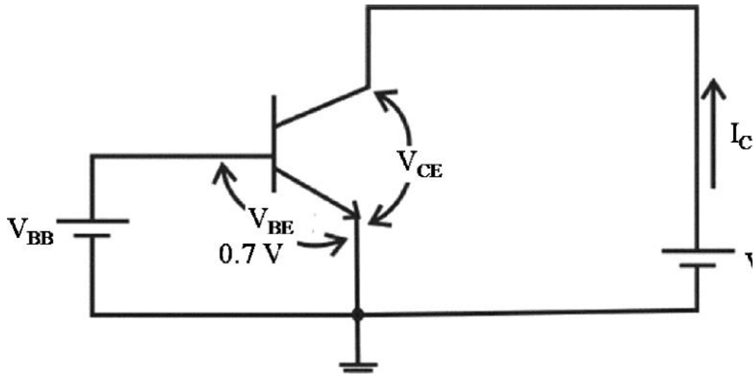
$$5\ k\Omega \times 1\ mA = 5V$$

Hence it is observed that a change of 0.1v in the input gives a change of 5v in the output, which means the voltage level of the signal is amplified.

Biasing of Transistor for Amplification

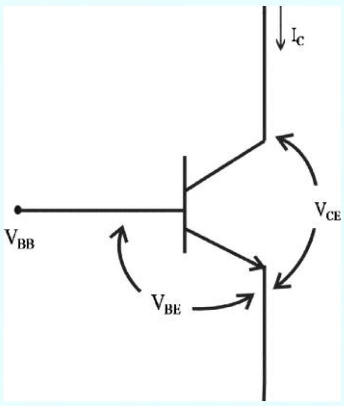
Usually, the input signal of an amplifier is AC. The AC signals have both positive and negative values. To keep the transistor in the ON condition and to have the base current flowing, the base to emitter voltage of the transistor should be kept around 0.7 V. This happens for the positive values above 0.7 V of the input signal. But for the input voltages below 0.7 V (including the entire negative values), the transistor can be made conducting by applying a DC voltage at the base of the transistor and it is called biasing.

Consider the circuit shown below.The emitter base junction is forward biased by V_{BB} and the collector base junction is reverse biased by V_{cc}, for operating the transistor in an active region. The V_{cc} should be greater than V_{BB} in order to reverse bias the collector-base junction.

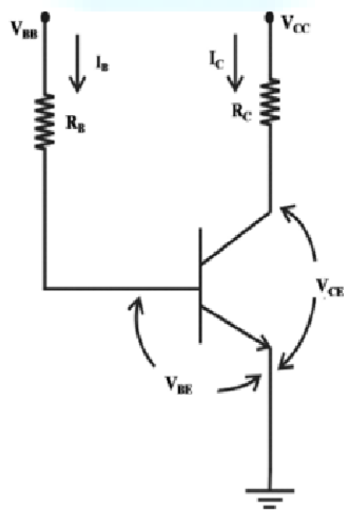


Emitter base junction forward biased and collector base junction reverse biased.

To keep the transistor in the active region, the value of V_{BE} should be between 0.6 V to 0.7 V. To get the desired base current the value of V_{BE} must be fixed precisely. A resistor of proper value can be used in series with the voltage source V_{BB}, to get the required base current. To fix the operating point (V and V_{CE}) at the required value, a resistor R_c is placed at the collector terminal.



The biasing circuit can be redrawn as



The transistor can be placed in the active region of operation by choosing appropriate values of V_{cc} and R_c.

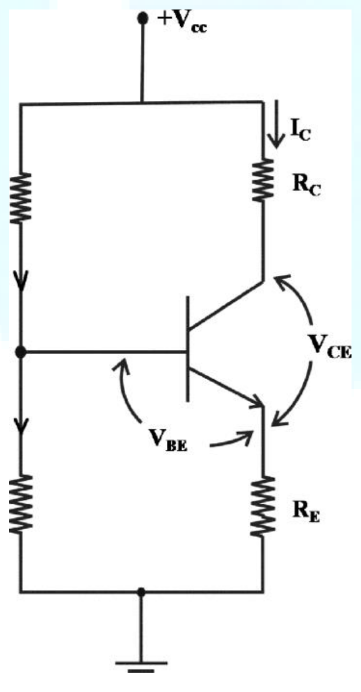
But the fixed biasing has the following disadvantages

1) The operating point depends on beta of the transistor
2) It cannot stop thermal runaway.

Flow of collector current produces heat in the collector junction. This increases the temperature. Hence more minority carriers are generated in CB junction. This increases the reverse leakage current and hence the collector current. As the collector current increases, it will again result in an increase in collector current. This process goes on and finally, the temperature at the collector junction increases to such an extent causing the junction to breakdown. This process is called thermal runaway

Voltage Divider biasing Circuit

Voltage divider biasing circuit is the most widely used biasing circuit. Compared to the fixed biasing circuit, voltage divider biasing circuit contains an additional resistor R_2 between the base and the ground. R_1-R_2 forms the potential divider circuit. By suitably selecting the values of R_1 and R_2 the operating point of the transistor can be fixed.

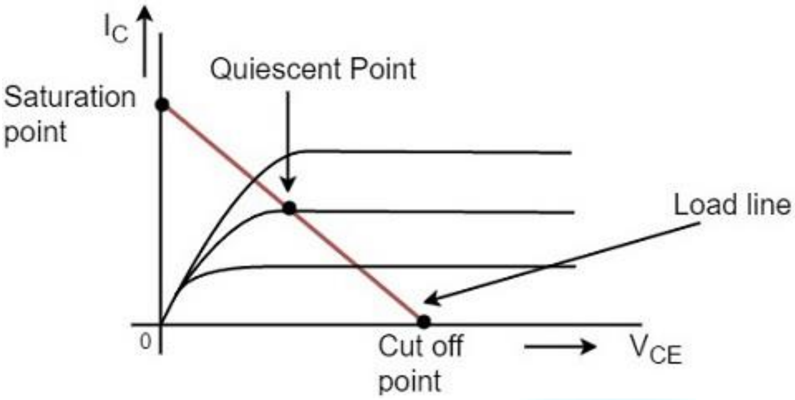


Operating Point

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 following graph shows how to represent the operating point



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.

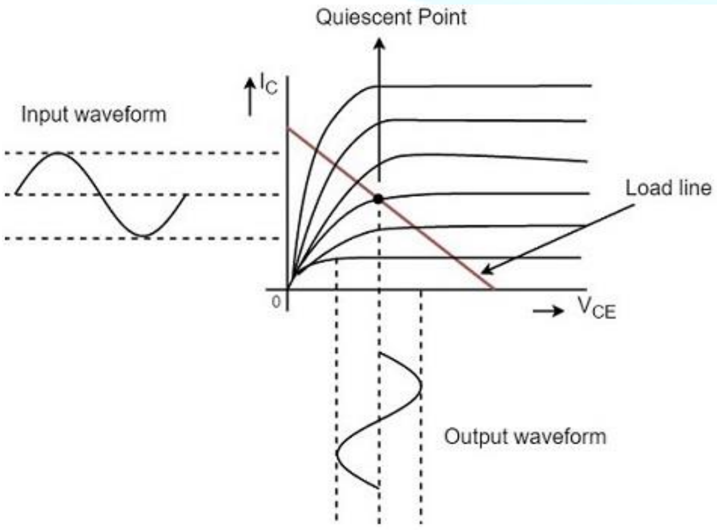
Fixing the Operating Point

In order to work as an amplifier, the operating point of the transistor should be in the active region.

Faithful Amplification

The process of increasing the signal strength is called as **Amplification**. This amplification when done without any loss in the components of the signal, is called as **Faithful amplification**.

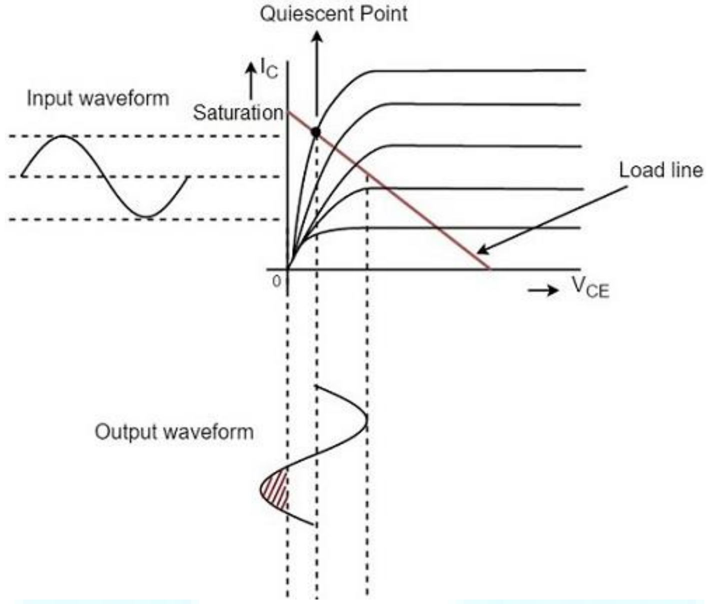
Faithful amplification is the process of obtaining complete portions of input signal by increasing the signal strength. This is done when AC signal is applied at its input.



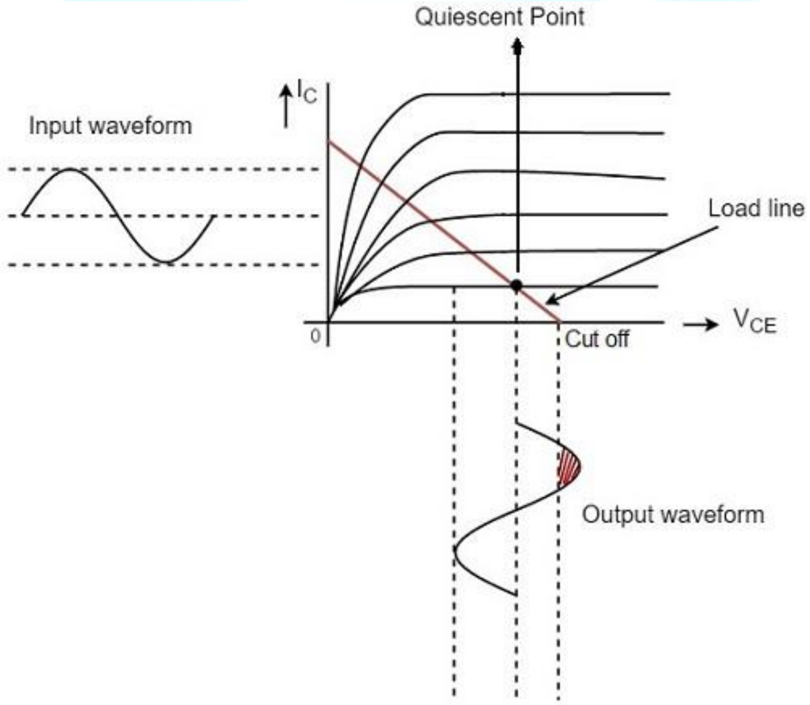
In the above graph, the input signal applied is completely amplified and reproduced without any losses. This can be understood as **Faithful Amplification**.

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.

If the operating point is considered near saturation point, then the amplification will be as under.



If the operation point is considered near cut off point, then the amplification will be as under.



Hence the placement of operating point is an important factor to achieve faithful amplification. But for the transistor to function properly as an amplifier, its input circuit (i.e., the base-emitter junction) remains forward biased and its output circuit (i.e., collector-base junction) remains reverse biased.

The amplified signal thus contains the same information as in the input signal whereas the strength of the signal is increased.

Key factors for Faithful Amplification

To ensure faithful amplification, the following basic conditions must be satisfied.

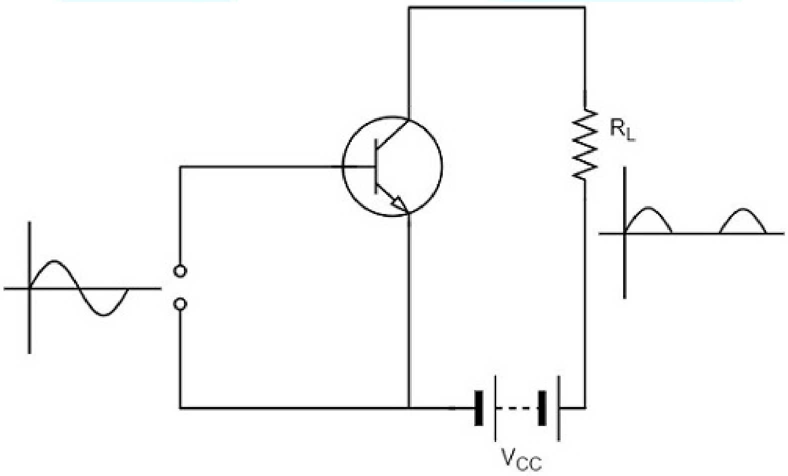
- Proper zero signal collector current
- Minimum proper base-emitter voltage (V_{BE}) at any instant.
- Minimum proper collector-emitter voltage (V_{CE}) at any instant.

The fulfilment of these conditions ensures that the transistor works over the active region having input forward biased and output reverse biased.

Proper Zero Signal Collector Current

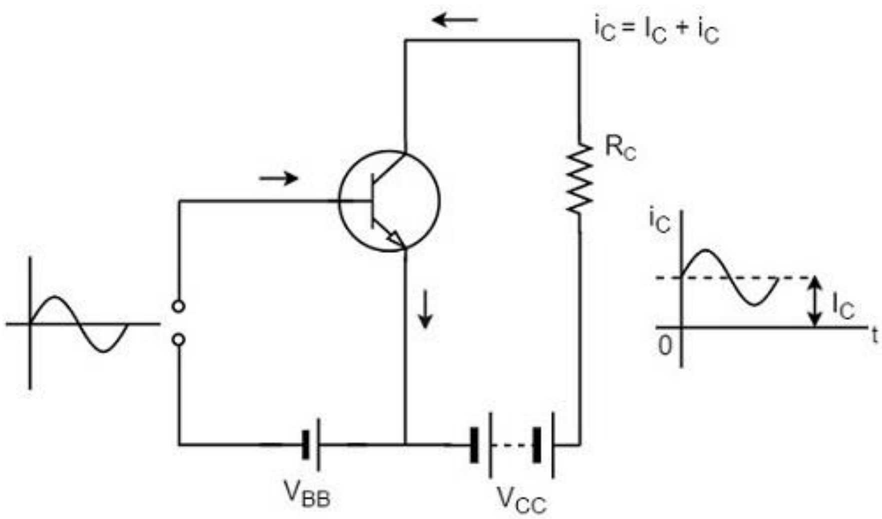
In order to understand this, let us consider a NPN transistor circuit as shown in the figure below. The base-emitter junction is forward biased and the collector-emitter junction is reverse biased. When a signal is applied at the input, the base-emitter junction of the NPN transistor gets forward biased for positive half cycle of the input and hence it appears at the output.

For negative half cycle, the same junction gets reverse biased and hence the circuit doesn't conduct. This leads to **unfaithful amplification** as shown in the figure below.



Let us now introduce a battery V_{BB} in the base circuit. The magnitude of this voltage should be such that the base-emitter junction of the transistor should remain in forward biased, even for negative half cycle of input signal. When no input signal is applied, a DC current flows in the circuit, due to V_{BB}. This is known as **zero signal collector current** I_C.

During the positive half cycle of the input, the base-emitter junction is more forward biased and hence the collector current increases. During the negative half cycle of the input, the input junction is less forward biased and hence the collector current decreases. Hence both the cycles of the input appear in the output and hence **faithful amplification** results, as shown in the below figure.



Hence for faithful amplification, proper zero signal collector current must flow. The value of zero signal collector current should be at least equal to the maximum collector current due to the signal alone.

Proper Minimum V_{BE} at any instant

The minimum base to emitter voltage V_{BE} should be greater than the cut-in voltage for the junction to be forward biased. The minimum voltage needed for a silicon transistor to conduct is 0.7v and for a germanium transistor to conduct is 0.5v. If the base-emitter voltage V_{BE} is greater than this voltage, the potential barrier is overcome and hence the base current and collector currents increase sharply.

Hence if V_{BE} falls low for any part of the input signal, that part will be amplified to a lesser extent due to the resultant small collector current, which results in unfaithful amplification.

Proper Minimum V_{CE} at any instant

To achieve a faithful amplification, the collector emitter voltage V_{CE} should not fall below the cut-in voltage, which is called as **Knee Voltage**. If V_{CE} is lesser than the knee voltage, the collector base junction will not be 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.

Therefore, if V_{CE} falls low for any part of the input signal, that part will be multiplied to a lesser extent, resulting 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.

Performance of Amplifier

As the common emitter mode of connection is mostly adopted, let us first understand a few important terms with reference to this mode of connection.

Input Resistance

As the input circuit is forward biased, the input resistance will be low. The input resistance is the opposition offered by the base-emitter junction to the signal flow.

By definition, it is the ratio of small change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage.

$$\text{Input resistance, } Ri = \Delta V_{BE} / \Delta I_B$$

Where R_i = input resistance, V_{BE} = base-emitter voltage, and I_B = base current.

Output Resistance

The output resistance of a transistor amplifier is very high. The collector current changes very slightly with the change in collector-emitter voltage.

By definition, it is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current.

$$\text{Output resistance, } Ro = \Delta V_{CE} / \Delta I_C$$

Where R_o = Output resistance, V_{CE} = Collector-emitter voltage, and I_C = Collector-emitter voltage.

Effective Collector Load

The load is connected at the collector of a transistor and for a single-stage amplifier, the output voltage is taken from the collector of the transistor and for a multi-stage amplifier, the same is collected from a cascaded stages of transistor circuit.

By definition, it is the total load as seen by the a.c. collector current. In case of single stage amplifiers, the effective collector load is a parallel combination of R_C and R_o.

$$\text{Effective Collector Load, } RAC = RC//Ro$$

$$(R_C \times Ro)/(R_C + Ro) = RAC$$

Current Gain

The gain in terms of current when the changes in input and output currents are observed, is called as **Current gain**. By definition, it is the ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B).

$$\text{Current gain, } \beta = \Delta IC\Delta IB\beta = \Delta IC\Delta IB$$

The value of β ranges from 20 to 500. The current gain indicates that input current becomes β times in the collector current.

Voltage Gain

The gain in terms of voltage when the changes in input and output currents are observed, is called as **Voltage gain**. By definition, it is the ratio of change in output voltage (ΔV_{CE}) to the change in input voltage (ΔV_{BE}).

$$\text{Voltage gain, } A_V = \Delta V_{CE} / \Delta V_{BE}$$

$$= \frac{\text{Change in output current} \times \text{effective load}}{\text{Change in input current} \times \text{input resistance}}$$

$= \Delta I_C \times R_{AC} / \Delta I_B \times R_i$
$= (\Delta I_C / \Delta I_B) \times (R_{AC} / R_i)$
$= \beta \times R_{AC} / R_i$

For a single stage, $R_{AC} = R_C$.

However, for Multistage,

$RAC = R_C \times R_i / R_C + R_i$

Where R_i is the input resistance of the next stage.

Power Gain

The gain in terms of power when the changes in input and output currents are observed, is called as **Power gain**.

By definition, it is the ratio of output signal power to the input signal power.

Power gain, $A_P = (\Delta I_C)^2 \times R_{AC} / (\Delta I_B)^2 \times Ri$
$= (\Delta I_C / \Delta I_B) \times (\Delta I_C \times R_{AC}) / (\Delta I_B \times R_i)$

= Current gain × Voltage gain

Hence these are all the important terms which refer the performance of amplifiers.

Multi-Stage Transistor Amplifier

In practical applications, the output of a single state amplifier is usually insufficient, though it is a voltage or power amplifier. Hence they are replaced by **Multi-stage transistor amplifiers**.

In Multi-stage amplifiers, the output of first stage is coupled to the input of next stage using a coupling device. These coupling devices can usually be a capacitor or a transformer. This process of joining two amplifier stages using a coupling device can be called as **Cascading**.

The following figure shows a two-stage amplifier connected in cascade.

The overall gain is the product of voltage gain of individual stages.

$V = AV_1 \times AV_2 = \frac{V2}{V1} x \frac{V0}{V2} = V_0 V_1$

Where A_V = Overall gain, A_{V1} = Voltage gain of 1st stage, and A_{V2} = Voltage gain of 2nd stage.

If there are **n** number of stages, the product of voltage gains of those **n** stages will be the overall gain of that multistage amplifier circuit.

Purpose of coupling device

The basic purposes of a coupling device are

- To transfer the AC from the output of one stage to the input of next stage.
- To block the DC to pass from the output of one stage to the input of next stage, which means to isolate the DC conditions.

Types of Coupling

Joining one amplifier stage with the other in cascade, using coupling devices form a **multi-stage amplifier circuit**. There are **four** basic methods of coupling, using these coupling devices such as resistors, capacitors, transformers etc. Let us have an idea about them.

Resistance-Capacitance Coupling

This is the mostly used method of coupling, formed using simple **resistor-capacitor** combination. The capacitor which allows AC and blocks DC is the main coupling element used here.

The coupling capacitor passes the AC from the output of one stage to the input of its next stage. While blocking the DC components from DC bias voltages to effect the next stage. Let us get into the details of this method of coupling in the coming chapters.

Impedance Coupling

The coupling network that uses **inductance** and **capacitance** as coupling elements can be called as Impedance coupling network.

In this impedance coupling method, the impedance of coupling coil depends on its inductance and signal frequency. This method is not so popular and is seldom employed.

Transformer Coupling

The coupling method that uses a **transformer as the coupling** device can be called as Transformer coupling. There is no capacitor used in this method of coupling because the transformer itself conveys the AC component directly to the base of second stage.

The secondary winding of the transformer provides a base return path and hence there is no need of base resistance. This coupling is popular for its efficiency and its impedance matching and hence it is mostly used.

Direct Coupling

If the previous amplifier stage is connected to the next amplifier stage directly, it is called as **direct coupling**. The individual amplifier stage bias conditions are so designed that the stages can be directly connected without DC isolation.

The direct coupling method is mostly used when the load is connected in series, with the output terminal of the active circuit element. For example, head-phones, loud speakers etc.

Role of Capacitors in Amplifiers

Other than the coupling purpose, there are other purposes for which few capacitors are especially employed in amplifiers. To understand this, let us know about the role of capacitors in Amplifiers.

The Input Capacitor C_{in}

The input capacitor C_{in} present at the initial stage of the amplifier, couples AC signal to the base of the transistor. This capacitor C_{in} if not present, the signal source will be in parallel to resistor R_2 and the bias voltage of the transistor base will be changed.

Hence C_{in} allows, the AC signal from source to flow into input circuit, without affecting the bias conditions.

The Emitter By-pass Capacitor C_e

The emitter by-pass capacitor C_e is connected in parallel to the emitter resistor. It offers a low reactance path to the amplified AC signal.

In the absence of this capacitor, the voltage developed across R_E will feedback to the input side thereby reducing the output voltage. Thus in the presence of C_e the amplified AC will pass through this.

Coupling Capacitor C_C

The capacitor C_C is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the operating point from shifting. This is also called as **blocking capacitor** because it does not allow the DC voltage to pass through it.

In the absence of this capacitor, R_C will come in parallel with the resistance R_1 of the biasing network of the next stage and thereby changing the biasing conditions of the next stage.

Amplifier Consideration

For an amplifier circuit, the overall gain of the amplifier is an important consideration. To achieve maximum voltage gain, let us find the most suitable transistor configuration for cascading.

CC Amplifier

- Its voltage gain is less than unity.
- It is not suitable for intermediate stages.

CB Amplifier

- Its voltage gain is less than unity.
- Hence not suitable for cascading.

CE Amplifier

- Its voltage gain is greater than unity.
- Voltage gain is further increased by cascading.

The characteristics of CE amplifier are such that, this configuration is very suitable for cascading in amplifier circuits. Hence most of the amplifier circuits use CE configuration.

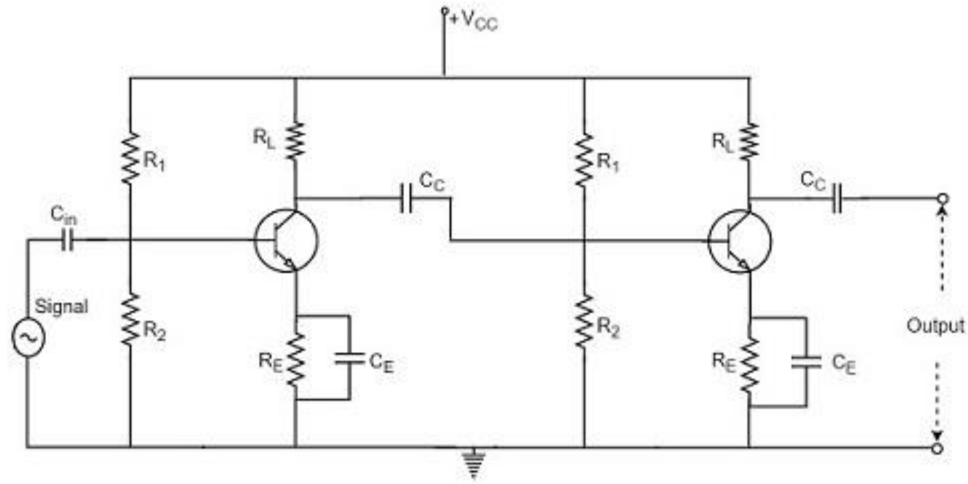
RC Coupling Amplifier

The resistance-capacitance coupling is, in short termed as RC coupling. This is the mostly used coupling technique in amplifiers.

Construction of a Two-stage RC Coupled Amplifier

The constructional details of a two-stage RC coupled transistor amplifier circuit are as follows. The two-stage amplifier circuit has two transistors, connected in CE configuration and a common power supply V_{CC} is used. The potential divider network R_1 and R_2 and the resistor R_e form the biasing and stabilization network. The emitter by-pass capacitor C_e offers a low reactance path to the signal.

The resistor R_L is used as a load impedance. The input capacitor C_{in} present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor C_C is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point. The figure below shows the circuit diagram of RC coupled amplifier.



Operation of RC Coupled Amplifier

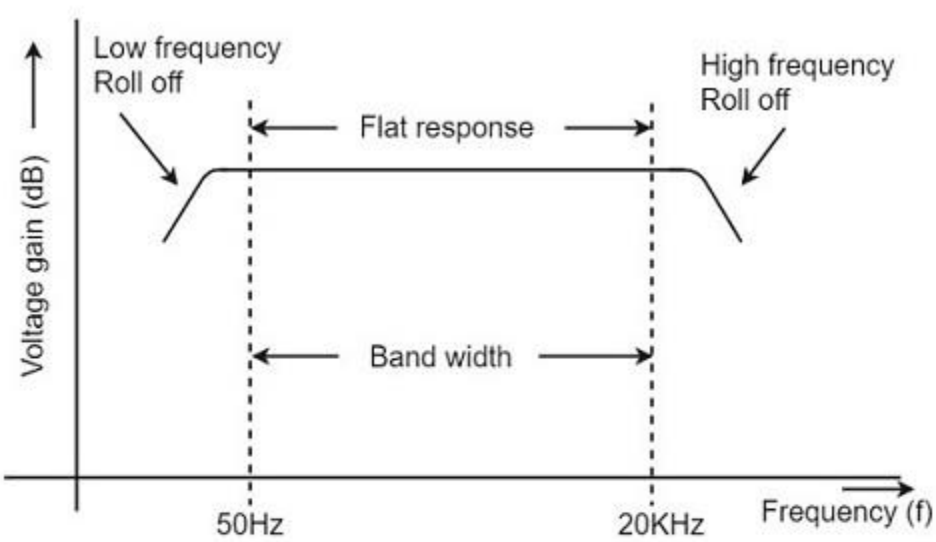
When an AC input signal is applied to the base of first transistor, it gets amplified and appears at the collector load R_L which is then passed through the coupling capacitor C_C to the next stage. This becomes the input of the next stage, whose amplified output again appears across its collector load. Thus, the signal is amplified in stage by stage action.

The important point that has to be noted here is that the total gain is less than the product of the gains of individual stages. This is because when a second stage is made to follow the first stage, the **effective load resistance** of the first stage is reduced due to the shunting effect of the input resistance of the second stage. Hence, in a multistage amplifier, only the gain of the last stage remains unchanged.

As we consider a two-stage amplifier here, the output phase is same as input. Because the phase reversal is done two times by the two stage CE configured amplifier circuit.

Frequency Response of RC Coupled Amplifier

Frequency response curve is a graph that indicates the relationship between voltage gain and function of frequency. The frequency response of a RC coupled amplifier is as shown in the following graph.



From the above graph, it is understood that the frequency rolls off or decreases for the frequencies below 50Hz and for the frequencies above 20 KHz. whereas the voltage gain for the range of frequencies between 50Hz and 20 KHz is constant.

$X_C=1/2\pi fc$

It means that the capacitive reactance is inversely proportional to the frequency.

At Low frequencies (i.e. below 50 Hz)

The capacitive reactance is inversely proportional to the frequency. At low frequencies, the reactance is quite high. The reactance of input capacitor C_{in} and the coupling capacitor C_C are so high that only small part of the input signal is allowed. The reactance of the emitter by pass capacitor C_E is also very high during low frequencies. Hence it cannot shunt the emitter resistance effectively. With all these factors, the voltage gain rolls off at low frequencies.

At High frequencies (i.e. above 20 KHz)

Again considering the same point, we know that the capacitive reactance is low at high frequencies. So, a capacitor behaves as a short circuit, at high frequencies. As a result of this, the loading effect of the next stage increases, which reduces the voltage gain. Along with this, as the capacitance of emitter diode decreases, it increases the base current of the transistor due to which the current gain (β) reduces. Hence the voltage gain rolls off at high frequencies.

At Mid-frequencies (i.e. 50 Hz to 20 KHz)

The voltage gain of the capacitors is maintained constant in this range of frequencies, as shown in figure. If the frequency increases, the reactance of the capacitor C_c decreases which tends to increase the gain. But this lower capacitance reactive increases the loading effect of the next stage by which there is a reduction in gain.

Due to these two factors, the gain is maintained constant.

Advantages of RC Coupled Amplifier

The following are the advantages of RC coupled amplifier.

- The frequency response of RC amplifier provides constant gain over a wide frequency range, hence most suitable for audio applications.
- The circuit is simple and has lower cost because it employs resistors and capacitors which are cheap.
- It becomes more compact with the upgrading technology.

Disadvantages of RC Coupled Amplifier

The following are the disadvantages of RC coupled amplifier.

- The voltage and power gain are low because of the effective load resistance.
- They become noisy with age.
- Due to poor impedance matching, power transfer will be low.

Applications of RC Coupled Amplifier

The following are the applications of RC coupled amplifier.

- They have excellent audio fidelity over a wide range of frequency.
- Widely used as Voltage amplifiers
- Due to poor impedance matching, RC coupling is rarely used in the final stages.

Transformer Coupled Amplifier

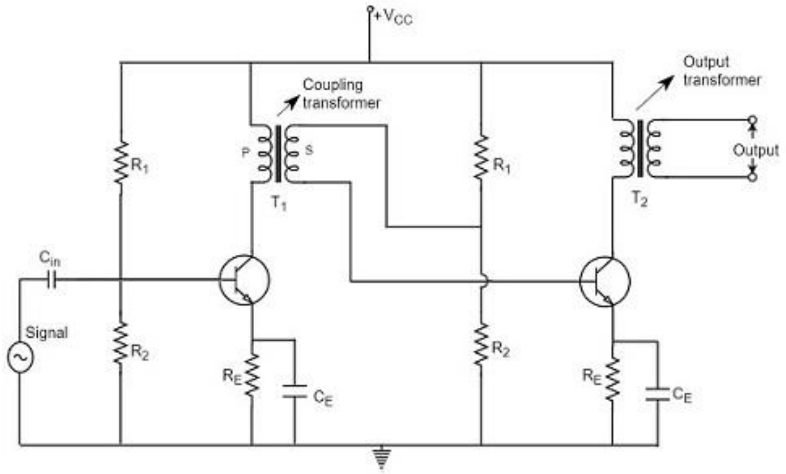
In a transformer-coupled amplifier, the stages of amplifier are coupled using a transformer.

Construction of Transformer Coupled Amplifier

The amplifier circuit in which, the previous stage is connected to the next stage using a coupling transformer, is called as Transformer coupled amplifier.

The coupling transformer T_1 is used to feed the output of 1st stage to the input of 2nd stage. The collector load is replaced by the primary winding of the transformer. The secondary winding is connected between the potential divider and the base of 2nd stage, which provides the input to the 2nd stage. Instead of coupling capacitor like in RC coupled amplifier, a transformer is used for coupling any two stages, in the transformer coupled amplifier circuit.

The figure below shows the circuit diagram of transformer coupled amplifier.



The potential divider network R_1 and R_2 and the resistor R_e together form the biasing and stabilization network. The emitter by-pass capacitor C_e offers a low reactance path to the signal. The resistor R_L is used as a load impedance. The input capacitor C_{in} present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor C_C is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point.

Operation of Transformer Coupled Amplifier

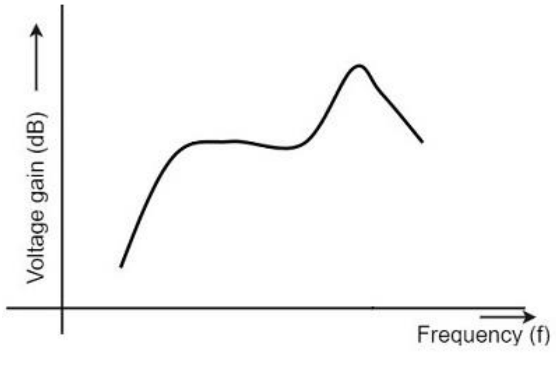
When an AC signal is applied to the input of the base of the first transistor then it gets amplified by the transistor and appears at the collector to which the primary of the transformer is connected.

The transformer which is used as a coupling device in this circuit has the property of impedance changing, which means the low resistance of a stage (or load) can be reflected as a high load resistance to the previous stage. Hence the voltage at the primary is transferred according to the turn's ratio of the secondary winding of the transformer.

This transformer coupling provides good impedance matching between the stages of amplifier. The transformer coupled amplifier is generally used for power amplification.

Frequency Response of Transformer Coupled Amplifier

The figure below shows the frequency response of a transformer coupled amplifier. The gain of the amplifier is constant only for a small range of frequencies. The output voltage is equal to the collector current multiplied by the reactance of primary.



At low frequencies, the reactance of primary begins to fall, resulting in decreased gain. At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain.

So, the amplification of audio signals will not be proportionate and some distortion will also get introduced, which is called as **Frequency distortion**.

Advantages of Transformer Coupled Amplifier

The following are the advantages of a transformer coupled amplifier −

- An excellent impedance matching is provided.
- Gain achieved is higher.
- There will be no power loss in collector and base resistors.
- Efficient in operation.

Disadvantages of Transformer Coupled Amplifier

The following are the disadvantages of a transformer coupled amplifier −

- Though the gain is high, it varies considerably with frequency. Hence a poor frequency response.
- Frequency distortion is higher.
- Transformers tend to produce hum noise.
- Transformers are bulky and costly.

Applications

The following are the applications of a transformer coupled amplifier −

- Mostly used for impedance matching purposes.
- Used for Power amplification.
- Used in applications where maximum power transfer is needed.

Direct Coupled Amplifier

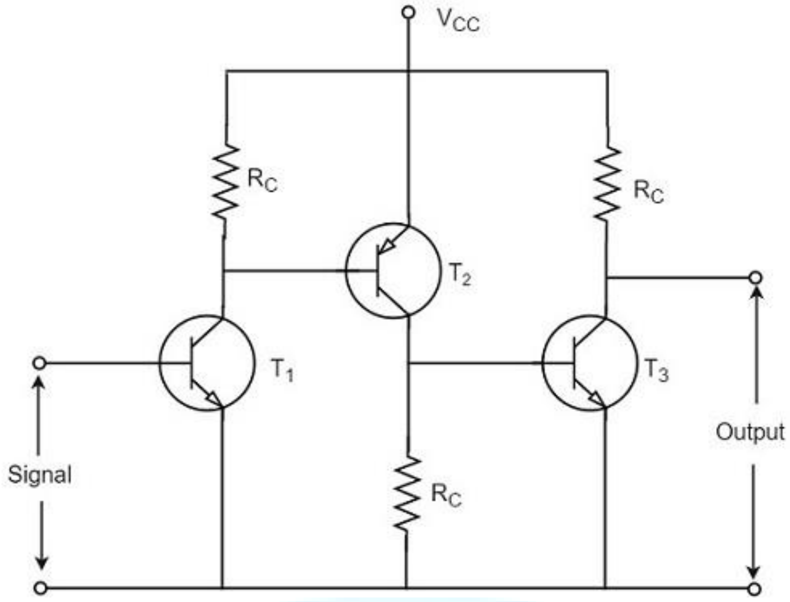
The other type of coupling amplifier is the direct coupled amplifier, which is especially used to amplify lower frequencies, such as amplifying photo-electric current or thermo-couple current or so.

Direct Coupled Amplifier

As no coupling devices are used, the coupling of the amplifier stages is done directly and hence called as **Direct coupled amplifier**.

Construction

The figure below indicates the three staged direct coupled transistor amplifier. The output of first stage transistor T_1 is connected to the input of second stage transistor T_2.



The transistor in the first stage will be an NPN transistor, while the transistor in the next stage will be a PNP transistor and so on. This is because, the variations in one transistor tend to cancel the variations in the other. The rise in the collector current and the variation in β of one transistor gets cancelled by the decrease in the other.

Operation

The input signal when applied at the base of transistor T_1, it gets amplified due to the transistor action and the amplified output appears at the collector resistor R_c of transistor T_1. This output is applied to the base of transistor T_2 which further amplifies the signal. In this way, a signal is amplified in a direct coupled amplifier circuit.

Advantages

The advantages of direct coupled amplifier are as follows.

- The circuit arrangement is simple because of minimum use of resistors.
- The circuit is of low cost because of the absence of expensive coupling devices.

Disadvantages

The disadvantages of direct coupled amplifier are as follows.

- It cannot be used for amplifying high frequencies.
- The operating point is shifted due to temperature variations.

Applications

The applications of direct coupled amplifier are as follows.

- Low frequency amplifications.
- Low current amplifications.

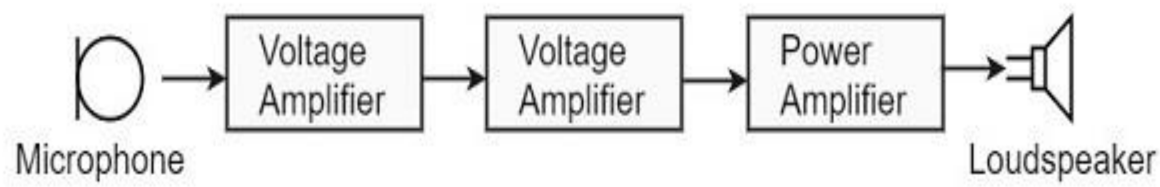
Comparisons

Sl.No	Particular	RC Coupling	Transformer Coupling	Direct Coupling
1	Frequency response	Excellent in audio frequency range	Poor	Best
2	Cost	Less	More	Least
3	Space and Weight	Less	More	Least
4	Impedance matching	Not good	Excellent	Good
5	Use	For voltage amplification	For Power amplification	For amplifying extremely low frequencies

Power Amplifiers

In practice, any amplifier consists of few stages of amplification. If we consider audio amplification, it has several stages of amplification, depending upon our requirement.

After the audio signal is converted into electrical signal, it has several voltage amplifications done, after which the power amplification of the amplified signal is done just before the loud speaker stage. This is clearly shown in the below figure.



While the voltage amplifier raises the voltage level of the signal, the power amplifier raises the power level of the signal. Besides raising the power level, it can also be said that a power amplifier is a device which converts DC power to AC power and whose action is controlled by the input signal.

The DC power is distributed according to the relation,

$$\text{DC power input} = \text{AC power output} + \text{losses}$$

Power Transistor

For such Power amplification, a normal transistor would not do. A transistor that is manufactured to suit the purpose of power amplification is called as a **Power transistor**.

A Power transistor differs from the other transistors, in the following factors.

- It is larger in size, in order to handle large powers.
- The collector region of the transistor is made large and a heat sink is placed at the collector-base junction in order to minimize heat generated.
- The emitter and base regions of a power transistor are heavily doped.
- Due to the low input resistance, it requires low input power.

Hence there is a lot of difference in voltage amplification and power amplification. So, let us now try to get into the details to understand the differences between a voltage amplifier and a power amplifier.

Difference between Voltage and Power Amplifiers

Voltage Amplifier

The function of a voltage amplifier is to raise the voltage level of the signal. A voltage amplifier is designed to achieve maximum voltage amplification.

The voltage gain of an amplifier is given by

$Av=\beta(Rc/Rin)$

The characteristics of a voltage amplifier are as follows –

- The base of the transistor should be thin and hence the value of β should be greater than 100.
- The resistance of the input resistor R_{in} should be low when compared to collector load R_C.
- The collector load R_C should be relatively high. To permit high collector load, the voltage amplifiers are always operated at low collector current.
- The voltage amplifiers are used for small signal voltages.

Power Amplifier

The function of a power amplifier is to raise the power level of input signal. It is required to deliver a large amount of power and has to handle large current.

The characteristics of a power amplifier are as follows –

- The base of transistor is made thicken to handle large currents. The value of β being (β > 100) high.
- The size of the transistor is made larger, in order to dissipate more heat, which is produced during transistor operation.
- Transformer coupling is used for impedance matching.
- Collector resistance is made low.

The comparison between voltage and power amplifiers is given below :

Sl.No	Particular	Voltage Amplifier	Power Amplifier
1	β	High (>100)	Low (5 to 20)
2	RC	High (4-10 KΩ)	Low (5 to 20 Ω)
3	Coupling	Usually R-C coupling	Invariably transformer coupling
4	Input voltage	Low (a few m V)	High (2-4 V)
5	Collector current	Low (≈ 1 mA)	High (> 100 mA)
6	Power output	Low	High
7	Output impendence	High (≈ 12 K Ω)	Low (200 Ω)

Classification of Power Amplifiers

The Power amplifiers amplify the power level of the signal. This amplification is done in the last stage in audio applications. The applications related to radio frequencies employ radio power amplifiers. But the **operating point** of a transistor, plays a very important role in determining the efficiency of the amplifier. The **main classification** is done based on this mode of operation.

The classification is done based on their frequencies and also based on their mode of operation.

Classification Based on Frequencies

Power amplifiers are divided into two categories, based on the frequencies they handle. They are as follows.

- **Audio Power Amplifiers –** The audio power amplifiers raise the power level of signals that have audio frequency range (20 Hz to 20 KHz). They are also known as **Small signal power amplifiers**.
- **Radio Power Amplifiers –** Radio Power Amplifiers or tuned power amplifiers raise the power level of signals that have radio frequency range (3 KHz to 300 GHz). They are also known as **large signal power amplifiers**.

Classification Based on Mode of Operation

On the basis of the mode of operation, i.e., the portion of the input cycle during which collector current flows, the power amplifiers may be classified as follows.

- **Class A Power amplifier** – When the collector current flows at all times during the full cycle of signal, the power amplifier is known as **class A power amplifier**.
- **Class B Power amplifier** – When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as **class B power amplifier**.
- **Class C Power amplifier** – When the collector current flows for less than half cycle of the input signal, the power amplifier is known as **class C power amplifier**.

There forms another amplifier called Class AB amplifier, if we combine the class A and class B amplifiers so as to utilize the advantages of both.

Before going into the details of these amplifiers, let us have a look at the important terms that have to be considered to determine the efficiency of an amplifier.

Terms Considering Performance

The primary objective of a power amplifier is to obtain maximum output power. In order to achieve this, the important factors to be considered are collector efficiency, power dissipation capability and distortion. Let us go through them in detail.

Collector Efficiency

This explains how well an amplifier converts DC power to AC power. When the DC supply is given by the battery but no AC signal input is given, the collector output at such a condition is observed as **collector efficiency**.

The collector efficiency is defined as

η=average a.c power output / average d.c power input to transistor

For example, if the battery supplies 15W and AC output power is 3W. Then the transistor efficiency will be 20%.

The main aim of a power amplifier is to obtain maximum collector efficiency. Hence the higher the value of collector efficiency, the efficient the amplifier will be.

Power Dissipation Capacity

Every transistor gets heated up during its operation. As a power transistor handles large currents, it gets more heated up. This heat increases the temperature of the transistor, which alters the operating point of the transistor.

So, in order to maintain the operating point stability, the temperature of the transistor has to be kept in permissible limits. For this, the heat produced has to be dissipated. Such a capacity is called as Power dissipation capability.

Power dissipation capability can be defined as the ability of a power transistor to dissipate the heat developed in it. Metal cases called heat sinks are used in order to dissipate the heat produced in power transistors.

Distortion

A transistor is a non-linear device. When compared with the input, there occur few variations in the output. In voltage amplifiers, this problem is not pre-dominant as small currents are used. But in power amplifiers, as large currents are in use, the problem of distortion certainly arises.

Distortion is defined as the change of output wave shape from the input wave shape of the amplifier. An amplifier that has lesser distortion, produces a better output and hence considered efficient.

Feedbacks in Amplifiers

Feedback: When a fraction of output is fed back to the input circuit, it is known as feedback. The fraction of output may either be current or voltage. A feedback amplifier consists of two parts: an amplifier and a feedback circuit.

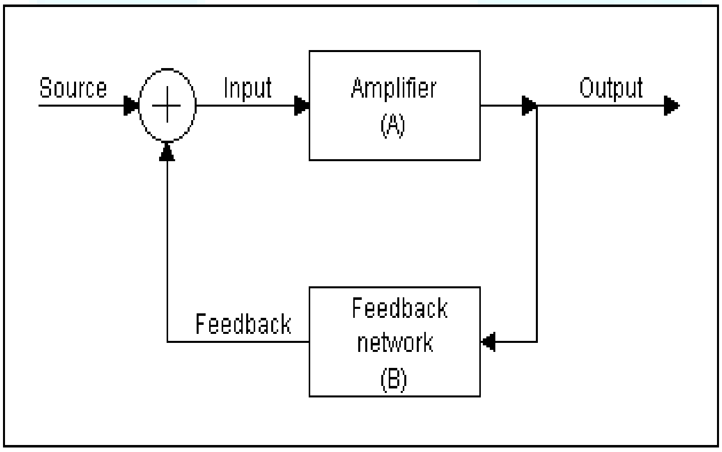
There are two types of feedback:

(1) Positive feedback

(2) Negative feedback

Positive Feedback: If the feedback voltage (or current) is so applied that it increases the input voltage (or current) then it is called positive feedback. In this case applied feedback voltage is in phase with input voltage. It is also known as regenerative or direct feedback. Positive feedback is used in oscillator circuits.

Negative Feedback: If the feedback voltage (or current) is so applied that it reduces the amplifier input then it is called negative feedback. In this case applied feedback voltage is 180° out of phase with input voltage. It is also known as degenerative or inverse feedback. Negative feedback is frequently used in amplifier circuits.



Application of transistor amplifier

- Used in optical fibre communication.
- Long-distance communication: Since the intensity of the output signal is high.
- The amplification of radio signals
- Wireless communication.

Transistor Oscillators

Introduction to Oscillators

An electronic oscillator is a circuit that produces a repetitive, oscillating electric signal, often a sine wave or a square wave. Oscillators generate AC signals of different frequencies by drawing power from a DC power supply. Oscillators generate frequencies ranging from a few Hz to several MHz. They are mainly used in electronic communication circuits such as radio, television, RADAR etc. In various communication circuits, oscillators are used to generate high frequency signals to carry messages. Oscillators are often characterized by the frequency of their output signal.

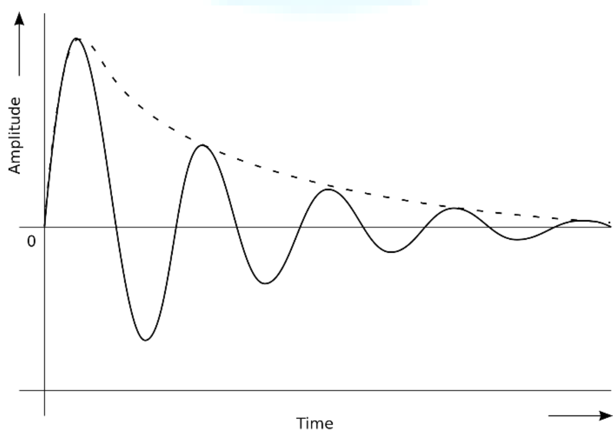
- An audio frequency (AF) oscillator produces frequencies in the audio range (20Hz - 20kHz).
- A radio frequency (RF) oscillator produces frequencies in the radio frequency range. (20 kHz -300 GHz)

Output of an oscillator may be a sine wave, square wave, sawtooth wave or pulses. Electronic oscillators may be broadly divided into following two groups:

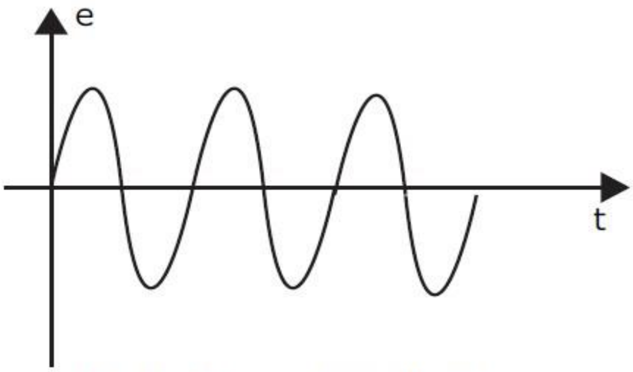
i. **Sinusoidal (or Harmonic) Oscillators:** Which produce an output having sine wave form.
ii. **Non-Sinusoidal Oscillators:** They produce an output which has rectangular, square or saw tooth waveform or is of pulse shape.

Sinusoidal Oscillators may be damped and undamped

Damped Oscillations: Oscillations whose amplitude keeps decreasing (or decaying) with time are called damped or decaying oscillations. Wave form of such oscillations are shown in figure given below.



Undamped Oscillations: Oscillations whose amplitude remains constant i.e. does not change with time are called undamped oscillations. Such oscillations are shown in figure given below.



(b) Undamped Oscillations

GENERATION OF SINE WAVES

In an electronic oscillator, the circuit which produces oscillations of any desired frequency is known as tank circuit.

The oscillation produced in the tank circuit of an oscillator is analogous to the oscillation of the pendulum. In the LC tank circuit, the oscillations are produced when the energy changes between the magnetic and the electric forms. The magnetic energy is stored in the inductor and the electric energy is stored in the capacitor.

Tank circuit

An LC circuit, also called a resonant circuit, tank circuit, or tuned circuit, consists of an inductor L and a capacitor C. When connected together, they can act as an electrical resonator. LC circuits are used either for generating signals at a particular frequency, or picking out a signal at a particular frequency from a more complex signal. They are the key components in the LC oscillators.

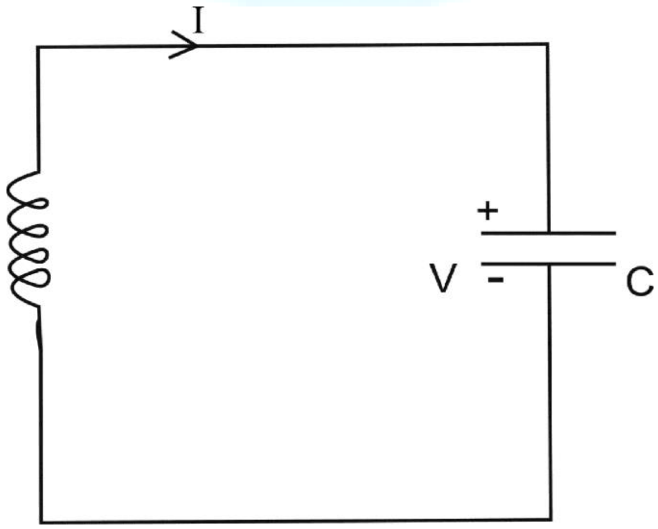


Fig : Tank Circuit

The LC circuit is an idealized model since it is assumed that, there is no dissipation of energy due to resistance of L. But the practical implementation of an LC circuit always includes loss of energy resulting from a small but non-zero resistance within the components (L and C) and connecting wires. The purpose of an LC circuit is usually to oscillate with minimal damping, so the resistance is made as low as possible. The operation of a tank circuit is explained below.

The capacitor stores energy in its electric field E and the inductor stores energy in its magnetic field B. If a charged capacitor is connected across an inductor, charge will start to flow through the inductor, building up a magnetic field around it. The voltage across the capacitor decreases due to the discharging of the capacitor. Eventually all the charge on the capacitor is lost and the voltage across it reaches zero. However, the current continues to flow, because the inductors resist changes in current. The energy to keep the current flowing is extracted from the magnetic field. So, the magnetic field begins to decline. As current flows, the capacitor will start charging, developing a voltage of opposite polarity. When the magnetic field is completely dissipated, the capacitor will be fully charged. The capacitor now starts discharging and the current flows charging the magnetic field. Then the cycle will begin again, with the current flowing in the opposite direction.

The charge flows back and forth between the plates of the capacitor, through the inductor. The energy oscillates back and forth between the capacitor and the inductor. These oscillations gradually decrease, as the energy is lost in the internal resistances and the oscillations die out soon. This action is similar to a pendulum swinging back and forth. The frequency of oscillations generated in the tank circuit is the resonant frequency of the LC circuit. If we plot the variation of the current in the inductor or the variation of voltage across the capacitor with respect to time, we get a sinusoidal graph. This changing voltage or current is the output of the oscillator.

Similar to the air friction that causes loss of energy during the oscillation of the pendulum, the electrical resistances of the inductor and the capacitor cause loss of energy in electronic oscillator. In order to get sustained oscillation, we need to supply energy continuously to the system. We give this energy to a pendulum in the form of regular external push, whereas it is given to an oscillator with the help of an amplifier in the circuit.

Basically, we have two types of oscillators. They are LC oscillators and RC oscillators. An oscillator has two parts - an amplifier and a feedback network. If the feedback circuit is an LC circuit, the oscillator is called LC oscillator and if the feedback circuit is an RC circuit, the oscillator is called an RC oscillator.

Frequency Selectivity

An LC tank circuit is a tuner which can select a frequency which is equal to its resonant frequency.

The total impedance of LC circuit is given by

$$Z = R + j\,(X_L - X_c)$$

where R is the total internal resistance of the inductor and the capacitor.

X_L is the reactance of the inductor.

X_c is the reactance of the capacitor.

Now the impedance of the circuit is minimum or the current in the circuit is maximum when X_L is equal to X_c.

$$So\ Z = R.$$

Thus, at a particular frequency for which X_c becomes equal to X_L, the circuit produces maximum response or current. This frequency is known as resonant frequency. In this condition, the circuit is said to be in resonance. For other frequencies, the response of the circuit will be less. The tank circuit thus selects its resonant frequency from all other frequencies by providing maximum response to this frequency. At resonant frequency,

$$X_L = X_c$$

Oscillator Applications

Oscillators are a cheap and easy way to generate specific Frequency of a signal. For example, an RC oscillator is used to generate a Low Frequency signal, an LC oscillator is used to generate a High Frequency signal, and an Op-Amp based oscillator is used to generate a stable frequency.

The frequency of oscillation can be varied by varying the component value with potentiometer arrangements.

Some common applications of oscillators include:

- Quartz watches (which uses a crystal oscillator)
- Used in various audio systems and video systems
- Used in various radio, TV, and other communication devices
- Used in computers, metal detectors, stun guns, inverters, ultrasonic and radio frequency applications.
- Used to generate clock pulses for microprocessors and micro-controllers
- Used in alarms and buzzes
- Used in metal detectors, stun guns, inverters, and ultrasonic
- Used to operate decorative lights (e.g., dancing lights)

Tuned Circuit Oscillators

Tuned circuit oscillators are the circuits that produce oscillations with the help of tuning circuits. The tuning circuits consists of an inductance L and a capacitor C. These are also known as **LC oscillators, resonant circuit oscillators** or **tank circuit oscillators**.

The tuned circuit oscillators are used to produce an output with frequencies ranging from 1 MHz to 500 MHz Hence these are also known as **R.F. Oscillators**. A BJT or a FET is used as an amplifier with tuned circuit oscillators. With an amplifier and an LC tank circuit, we can feedback a signal with right amplitude and phase to maintain oscillations.

Types of Tuned Circuit Oscillators

Most of the oscillators used in radio transmitters and receivers are of LC oscillators type. Depending upon the way the feedback is used in the circuit, the LC oscillators are divided as the following types.

- **Tuned-collector or Armstrong Oscillator** – It uses inductive feedback from the collector of a transistor to the base. The LC circuit is in the collector circuit of the transistor.
- **Tuned base Oscillator** – It uses inductive feedback. But the LC circuit is in the base circuit.
- **Hartley Oscillator** – It uses inductive feedback.
- **Colpitts Oscillator** – It uses capacitive feedback.
- **Clapp Oscillator** – It uses capacitive feedback.

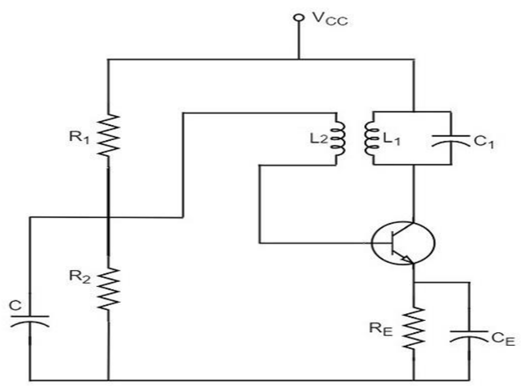
Tuned Collector Oscillator

Tuned collector oscillators are called so, because the tuned circuit is placed in the collector of the transistor amplifier. The combination of **L** and **C** form the tuned circuit or frequency determining circuit.

Construction

The resistors R_1, R_2 and R_E are used to provide d.c. bias to the transistor. The capacitors C_E and C are the by-pass capacitors. The secondary of the transformer provides a.c. feedback voltage that appears across the base-emitter junction of R_1 and R_2 is at a.c. ground due to by-pass capacitor C. In case, the capacitor was absent, a part of the voltage induced in the secondary of the transformer would drop across R_2 instead of completely going to the input of transistor.

As the CE configured transistor provides 180° phase shift, another 180° phase shift is provided by the transformer, which makes 360° phase shift between the input and output voltages. The following circuit diagram shows the arrangement of a tuned collector circuit.



Operation

Once the supply is given, the collector current starts increasing and charging of capacitor C takes place. When the capacitor is fully charged, it discharges through the inductance L_1. Now oscillations are produced. These oscillations induce some voltage in the secondary winding L_2. The frequency of voltage induced in the secondary winding is same as that of the tank circuit and its magnitude depends upon the number of turns in secondary winding and coupling between both the windings.

The voltage across L_2 is applied between base and emitter and appears in the amplified form in the collector circuit, thus overcoming the losses in the tank circuit. The number of turns of L_2 and coupling between L_1 and L_2 are so adjusted that oscillations across L_2 are amplified to a level just sufficient to supply losses to the tank circuit.

Tuned collector oscillators are widely used as the **local oscillator** in radio receivers.

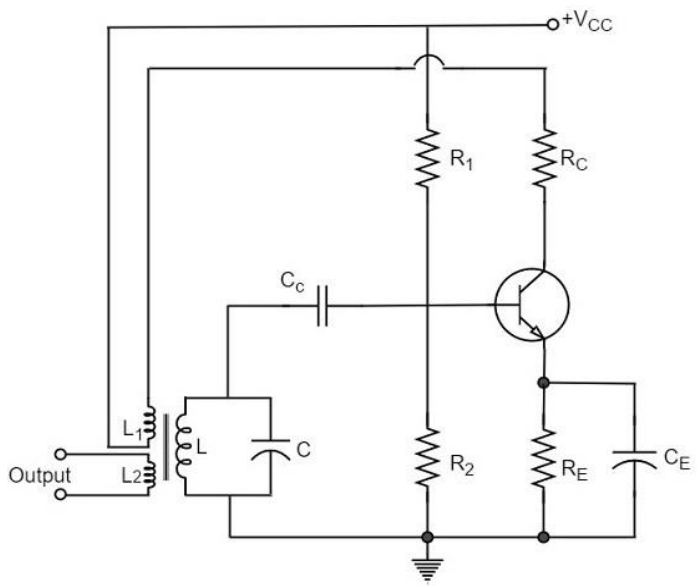
Tuned Base Oscillator

Tuned base oscillators are called so, because the tuned circuit is placed in the base of the transistor amplifier. The combination of **L** and **C** form the tuned circuit or frequency determining circuit.

Construction

The resistors R_1, R_2 and R_E are used to provide d.c. bias to the transistor. The parallel combination of R_e and C_e in the emitter circuit is the stabilizing circuit. C_C is the blocking capacitor. The capacitors C_E and C are the by-pass capacitors. The primary coil L and the secondary coil L_1 of RF transformer provides the required feedback to collector and base circuits.

As the CE configured transistor provides 180° phase shift, another 180° phase shift is provided by the transformer, which makes 360° phase shift between the input and output voltages. The following circuit diagram shows the arrangement of a tuned base oscillator circuit.



Operation

When the circuit is switched on, the collector current starts rising. As the collector is connected to the coil L_1, that current creates some magnetic field around it. This induces a voltage in the tuned circuit coil L. The feedback voltage produces an increase in emitter base voltage and base current. A further increase in collector current is thus achieved and the cycle continues until the collector current becomes saturated. In the meanwhile, the capacitor is fully charged.

When the collector current reaches saturation level, there is no feedback voltage in L. As the capacitor has been charged fully, it starts discharging through L. This decreases the emitter base bias and hence I_B and the collector current also decreases. By the time the collector current reaches cutoff, the capacitor C is fully charged with opposite polarity. As the transistor now gets off, the condenser C begins to discharge through L. This increases the emitter-base bias. As a result, the collector current increases.

The cycle repeats so long as enough energy is supplied to **meet the losses** in L.C. circuit. The frequency of oscillation is equal to the resonant frequency of L.C. circuit.

Drawback

The main **drawback** of tuned-base oscillator circuit is that, due to the low base-emitter resistance, which appears in shunt with the tuned circuit, the tank circuit gets loaded. This reduces its Q which in turn causes drift in oscillator frequency. Thus stability becomes poorer. Due to this reason, the tuned circuit is **not** usually **connected in base** circuit.

Hartley Oscillator

A very popular **local oscillator** circuit that is mostly used in **radio receivers** is the **Hartley Oscillator** circuit. The constructional details and operation of a Hartley oscillator are as discussed below.

Construction

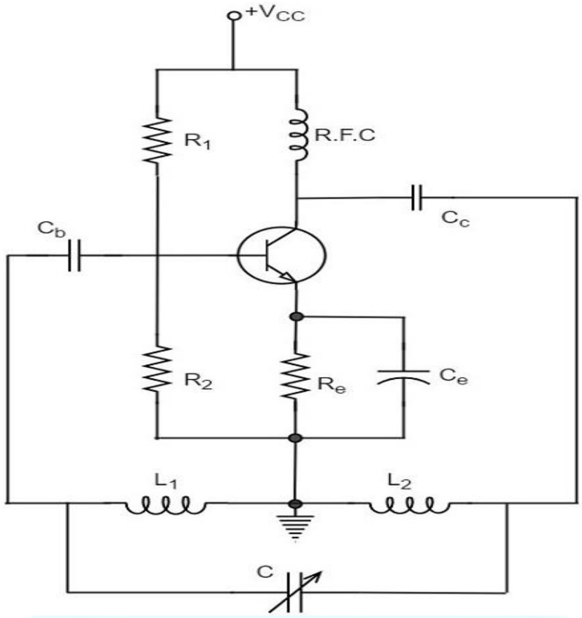
In the circuit diagram of a Hartley oscillator shown below, the resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

The capacitors C_c and C_b are employed to block d.c. and to provide an a.c. path. The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c. Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source

Tank Circuit

The frequency determining network is a parallel resonant circuit which consists of the inductors L_1 and L_2 along with a variable capacitor C. The junction of L_1 and L_2 are earthed. The coil L_1 has its one end connected to base via C_c and the other to emitter via C_e. So, L_2 is in the output circuit. Both the coils L_1 and L_2 are inductively coupled and together form an **Auto-transformer**.

The following circuit diagram shows the arrangement of a Hartley oscillator. The tank circuit is **shunt fed** in this circuit. It can also be a **series-fed**.



Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit. The oscillatory current in the tank circuit produces a.c. voltage across L_1.

The **auto-transformer** made by the inductive coupling of L_1 and L_2 helps in determining the frequency and establishes the feedback. As the CE configured transistor provides 180° phase shift, another 180° phase shift is provided by the transformer, which makes 360° phase shift between the input and output voltages.

This makes the feedback positive which is essential for the condition of oscillations. When the **loop gain |βA| of the amplifier is greater than one**, oscillations are sustained in the circuit.

Frequency

The equation for **frequency of Hartley oscillator** is given as

$f=1/2\pi\sqrt{(L_T C)}$

$L_T=L_1+L_2+2M$

Here, $\mathbf{L_T}$ is the total cumulatively coupled inductance; $\mathbf{L_1}$ and $\mathbf{L_2}$ represent inductances of 1st and 2nd coils; and **M** represents mutual inductance.

Mutual inductance is calculated when two windings are considered.

Advantages

The advantages of Hartley oscillator are

- Instead of using a large transformer, a single coil can be used as an auto-transformer.

- Frequency can be varied by employing either a variable capacitor or a variable inductor.
- Less number of components are sufficient.
- The amplitude of the output remains constant over a fixed frequency range.

Disadvantages

The disadvantages of Hartley oscillator are

- It cannot be a low frequency oscillator.
- Harmonic distortions are present.

Applications

The applications of Hartley oscillator are

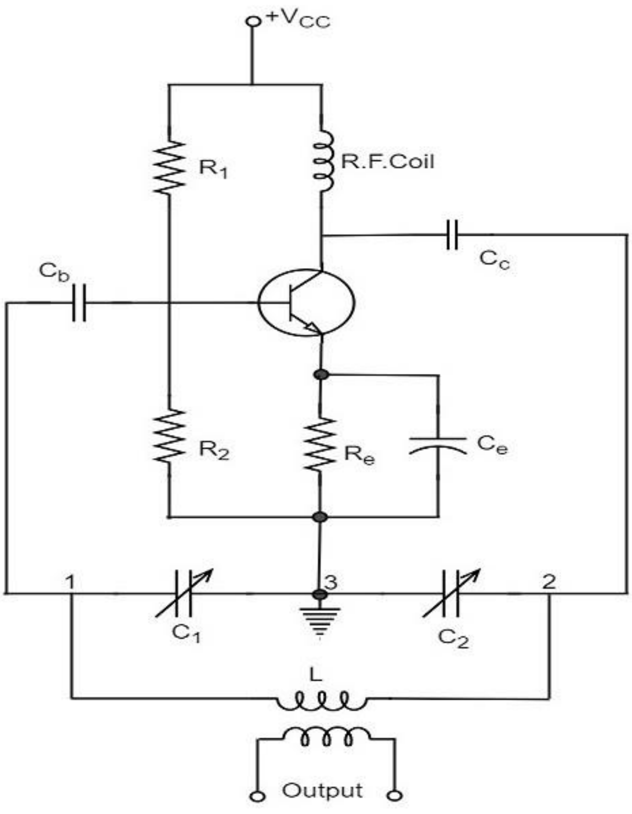
- It is used to produce a sinewave of desired frequency.
- Mostly used as a local oscillator in radio receivers.
- It is also used as R.F. Oscillator.

Colpitts Oscillator

A Colpitts oscillator looks just like the Hartley oscillator but the inductors and capacitors are replaced with each other in the tank circuit. The constructional details and operation of a Colpitts oscillator are as discussed below.

Construction

The circuit diagram of a Colpitts oscillator.



The resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

The capacitors C_c and C_b are employed to block d.c. and to provide an a.c. path. The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c. Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source.

Tank Circuit

The frequency determining network is a parallel resonant circuit which consists of variable capacitors C_1 and C_2 along with an inductor L. The junction of C_1 and C_2 are earthed. The capacitor C_1 has its one end connected to base via C_c and the other to emitter via C_e. the voltage developed across C_1 provides the regenerative feedback required for the sustained oscillations.

Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit. The oscillatory current in the tank circuit produces a.c. voltage across C_1 which are applied to the base emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit.

If terminal 1 is at positive potential with respect to terminal 3 at any instant, then terminal 2 will be at negative potential with respect to 3 at that instant because terminal 3 is grounded. Therefore, points 1 and 2 are out of phase by 180°.

As the CE configured transistor provides 180° phase shift, it makes 360° phase shift between the input and output voltages. Hence, feedback is properly phased to produce continuous Undamped oscillations. When the **loop gain |βA| of the amplifier is greater than one, oscillations are sustained** in the circuit.

Frequency

The equation for **frequency of Colpitts oscillator** is given as

$f=1/2\pi\sqrt{(LC_T)}$

C_T is the total capacitance of C_1 and C_2 connected in series.

$C_T=(C_1 \times C_2)/(C_1+C_2)$

Advantages

The advantages of Colpitts oscillator are as follows –

- Colpitts oscillator can generate sinusoidal signals of very high frequencies.
- It can withstand high and low temperatures.
- The frequency stability is high.
- Frequency can be varied by using both the variable capacitors.
- Less number of components are sufficient.

- The amplitude of the output remains constant over a fixed frequency range.

The Colpitts oscillator is designed to eliminate the disadvantages of Hartley oscillator and is known to have no specific disadvantages. Hence there are many applications of a Colpitts oscillator.

Applications

The applications of Colpitts oscillator are as follows –

- Colpitts oscillator can be used as High frequency sinewave generator.
- This can be used as a temperature sensor with some associated circuitry.
- Mostly used as a local oscillator in radio receivers.
- It is also used as R.F. Oscillator.
- It is also used in Mobile applications.
- It has got many other commercial applications.

Phase Shift Oscillators

One of the important features of an oscillator is that the feedback energy applied should be in correct phase to the tank circuit. The oscillator circuits discussed so far has employed inductor (L) and capacitor (C) combination, in the tank circuit or frequency determining circuit.

The LC combination in oscillators provide 180° phase shift and transistor in CE configuration provide 180° phase shift to make a total of 360° phase shift so that it would make a zero difference in phase.

Drawbacks of LC circuits

Though they have few applications, the **LC** circuits have few **drawbacks** such as

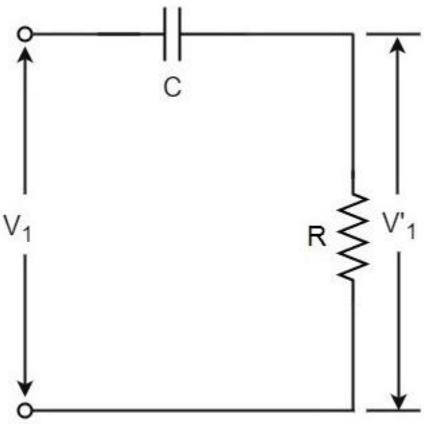
- Frequency instability
- Waveform is poor
- Cannot be used for low frequencies
- Inductors are bulky and expensive

We have another type of oscillator circuits, which are made by replacing the inductors with resistors. By doing so, the frequency stability is improved and a good quality waveform is obtained. These oscillators can also produce lower frequencies. As well, the circuit becomes neither bulky nor expensive.

All the drawbacks of **LC** oscillator circuits are thus eliminated in **RC** oscillator circuits. Hence the need for RC oscillator circuits arises. These are also called as **Phase–shift Oscillators**.

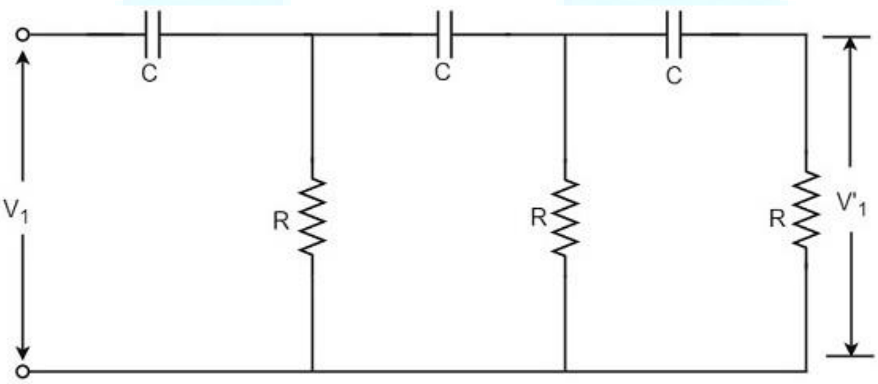
Principle of Phase-shift oscillators

The output voltage of an RC circuit for a sinewave input leads the input voltage. The phase angle by which it leads is determined by the value of RC components used in the circuit. The following circuit diagram shows a single section of an RC network.



The output voltage V_1' across the resistor R leads the input voltage applied input V_1 by some phase angle ϕ°. If R were reduced to zero, V_1' will lead the V_1 by 90° i.e., $\phi^\circ = 90^\circ$.

However, adjusting R to zero would be impracticable, because it would lead to no voltage across R. Therefore, in practice, R is varied to such a value that makes V_1' to lead V_1 by 60°. The following circuit diagram shows the three sections of the RC network.



Each section produces a phase shift of 60°. Consequently, a total phase shift of 180° is produced, i.e., voltage V_2 leads the voltage V_1 by 180°.

Phase-shift Oscillator Circuit

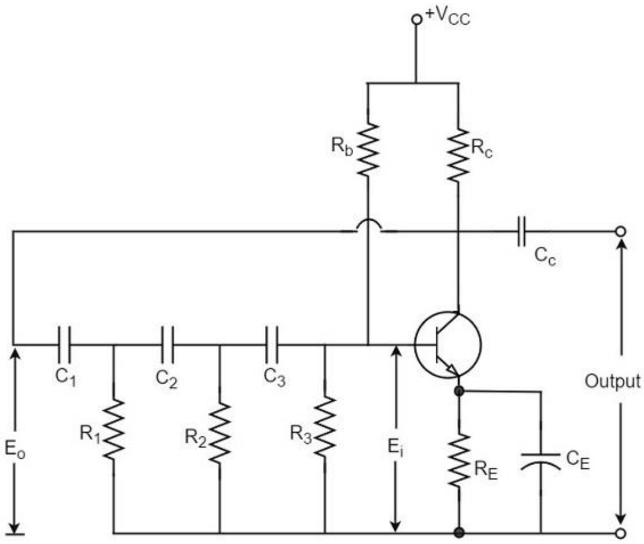
The oscillator circuit that produces a sine wave using a phase-shift network is called as a Phase-shift oscillator circuit. The constructional details and operation of a phase-shift oscillator circuit are as given below.

Construction

The phase-shift oscillator circuit consists of a single transistor amplifier section and a RC phase-shift network. The phase shift network in this circuit, consists of three RC sections.

At the resonant frequency f_o, the phase shift in each RC section is 60° so that the total phase shift produced by RC network is 180°.

The following circuit diagram shows the arrangement of an RC phase-shift oscillator.



The frequency of oscillations is given by

$f_o = 1/2\pi RC\sqrt{6}$

Where

$R_1=R_2=R_3=R$

$C_1=C_2=C_3=C$

Operation

The circuit when switched ON oscillates at the resonant frequency f_o. The output E_o of the amplifier is fed back to RC feedback network. This network produces a phase shift of 180° and a voltage E_i appears at its output. This voltage is applied to the transistor amplifier.

The feedback applied will be

$m = E_i/E_o$

The feedback is in correct phase, whereas the transistor amplifier, which is in CE configuration, produces a 180° phase shift. The phase shift produced by network and the transistor add to form a phase shift around the entire loop which is 360°.

Advantages

The advantages of RC phase shift oscillator are as follows –

- It does not require transformers or inductors.
- It can be used to produce very low frequencies.
- The circuit provides good frequency stability.

Disadvantages

The disadvantages of RC phase shift oscillator are as follows –

- Starting the oscillations is difficult as the feedback is small.
- The output produced is small.

Wien Bridge Oscillator

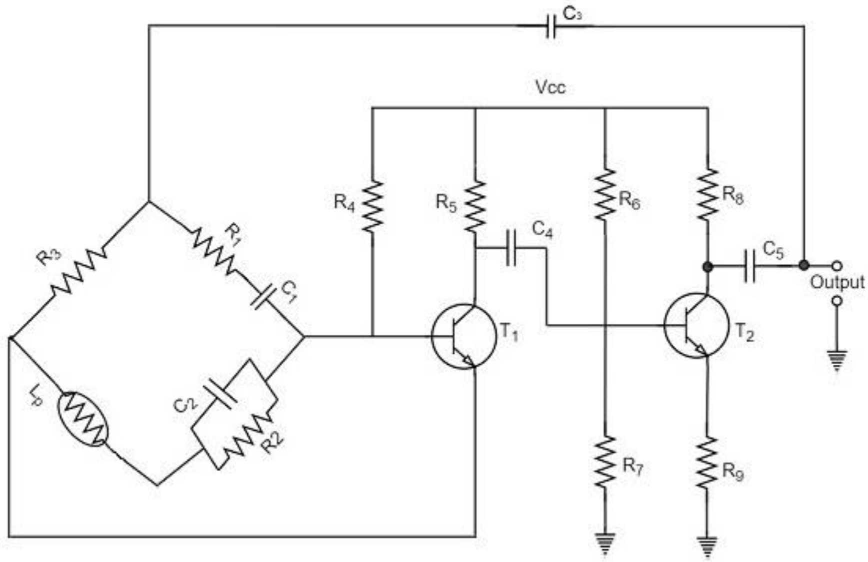
Another type of popular audio frequency oscillator is the Wien bridge oscillator circuit. This is mostly used because of its important features. This circuit is free from the **circuit fluctuations** and the **ambient temperature**.

The main advantage of this oscillator is that the frequency can be varied in the range of 10Hz to about 1MHz whereas in RC oscillators, the frequency is not varied.

Construction

The circuit construction of Wien bridge oscillator can be explained as below. It is a two-stage amplifier with RC bridge circuit. The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and the tungsten lamp L_p. Resistance R_3 and the lamp L_p are used to stabilize the amplitude of the output.

The following circuit diagram shows the arrangement of a Wien bridge oscillator.



The transistor T_1 serves as an oscillator and an amplifier while the other transistor T_2 serves as an inverter. The inverter operation provides a phase shift of 180°. This circuit provides positive feedback through R_1C_1, C_2R_2 to the transistor T_1 and negative feedback through the voltage divider to the input of transistor T_2.

The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

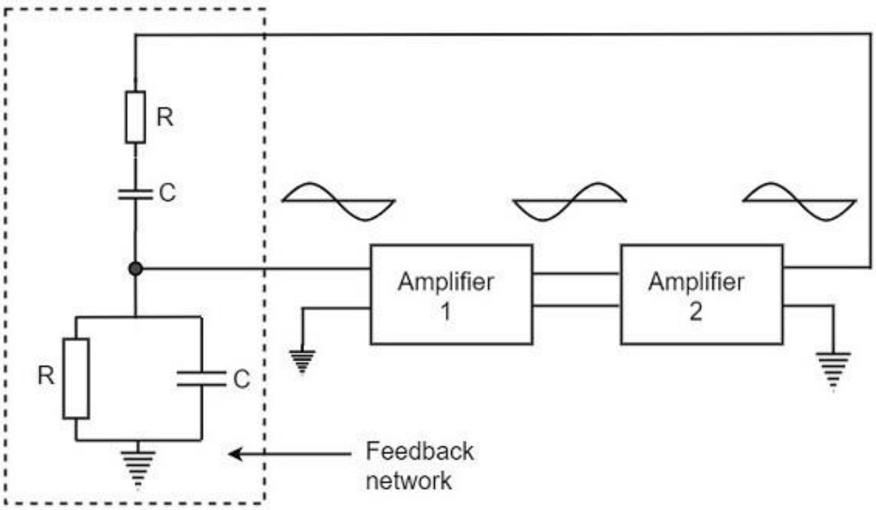
$f=1/2\pi\sqrt{(R_1C_1R_2C_2)}$

If $R_1 = R_2$ and $C_1 = C_2 = C$

Then,

$f = 1/2\pi RC$

The simplified circuit as follows



The oscillator consists of two stages of RC coupled amplifier and a feedback network. The voltage across the parallel combination of R and C is fed to the input of amplifier 1. The net phase shift through the two amplifiers is zero.

The usual idea of connecting the output of amplifier 2 to amplifier 1 to provide signal regeneration for oscillator is not applicable here as the amplifier 1 will amplify signals over a wide range of frequencies and hence direct coupling would result in poor frequency stability. By adding Wien bridge feedback network, the oscillator becomes sensitive to a particular frequency and hence frequency stability is achieved.

Operation

When the circuit is switched ON, the bridge circuit produces oscillations of the frequency stated above. The two transistors produce a total phase shift of 360° so that proper positive feedback is ensured. The negative feedback in the circuit ensures constant output. This is achieved by temperature sensitive tungsten lamp L_p. Its resistance increases with current.

If the amplitude of the output increases, more current is produced and more negative feedback is achieved. Due to this, the output would return to the original value. Whereas, if the output tends to decrease, reverse action would take place.

Advantages

The advantages of Wien bridge oscillator are as follows –

- The circuit provides good frequency stability.
- It provides constant output.
- The operation of circuit is quite easy.

- The overall gain is high because of two transistors.
- The frequency of oscillations can be changed easily.
- The amplitude stability of the output voltage can be maintained more accurately, by replacing R_2 with a thermistor.

Disadvantages

The disadvantages of Wien bridge oscillator are as follows −

- The circuit cannot generate very high frequencies.
- Two transistors and number of components are required for the circuit construction.

Crystal Oscillators

Whenever an oscillator is under continuous operation, its **frequency stability** gets affected. There occur changes in its frequency. The main factors that affect the frequency of an oscillator are

- Power supply variations
- Changes in temperature
- Changes in load or output resistance

In RC and LC oscillators the values of resistance, capacitance and inductance vary with temperature and hence the frequency gets affected. In order to avoid this problem, the piezo electric crystals are being used in oscillators.

The use of piezo electric crystals in parallel resonant circuits provide high frequency stability in oscillators. Such oscillators are called as **Crystal Oscillators**.

Crystal Oscillators

The principle of crystal oscillators depends upon the **Piezo electric effect**. The natural shape of a crystal is hexagonal. When a crystal wafer is cur perpendicular to X-axis, it is called as X-cut and when it is cut along Y-axis, it is called as Y-cut.

The crystal used in crystal oscillator exhibits a property called as Piezo electric property.

Piezo Electric Effect

The crystal exhibits the property that when a mechanical stress is applied across one of the faces of the crystal, a potential difference is developed across the opposite faces of the crystal. Conversely, when a potential difference is applied across one of the faces, a mechanical stress is produced along the other faces. This is known as **Piezo electric effect**.

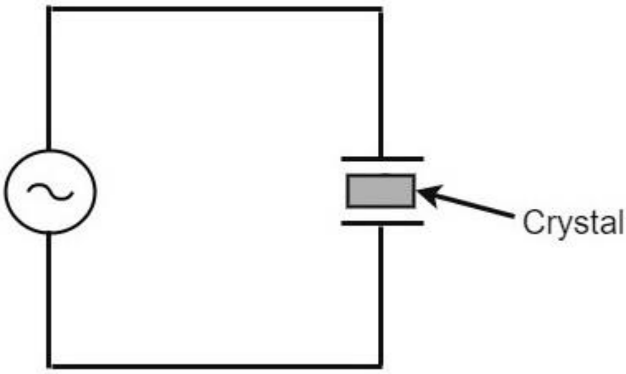
Certain crystalline materials like Rochelle salt, quartz and tourmaline exhibit piezo electric effect and such materials are called as **Piezo electric crystals.** Quartz is the most commonly used piezo electric crystal because it is inexpensive and readily available in nature.

When a piezo electric crystal is subjected to a proper alternating potential, it vibrates mechanically. The amplitude of mechanical vibrations becomes maximum when the frequency of alternating voltage is equal to the natural frequency of the crystal.

Working of a Quartz Crystal

In order to make a crystal work in an electronic circuit, the crystal is placed between two metal plates in the form of a capacitor. **Quartz** is the mostly used type of crystal because of its availability and strong nature while being inexpensive. The ac voltage is applied in parallel to the crystal.

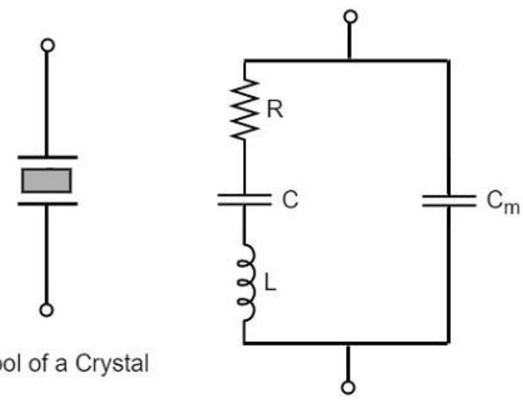
The circuit arrangement of a Quartz Crystal will be as shown below –



If an AC voltage is applied, the crystal starts vibrating at the frequency of the applied voltage. However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, **resonance** takes place and crystal vibrations reach a maximum value. This natural frequency is almost constant.

Equivalent circuit of a Crystal

If we try to represent the crystal with an equivalent electric circuit, we have to consider two cases, i.e., when it vibrates and when it doesn't. The figures below represent the symbol and electrical equivalent circuit of a crystal respectively.



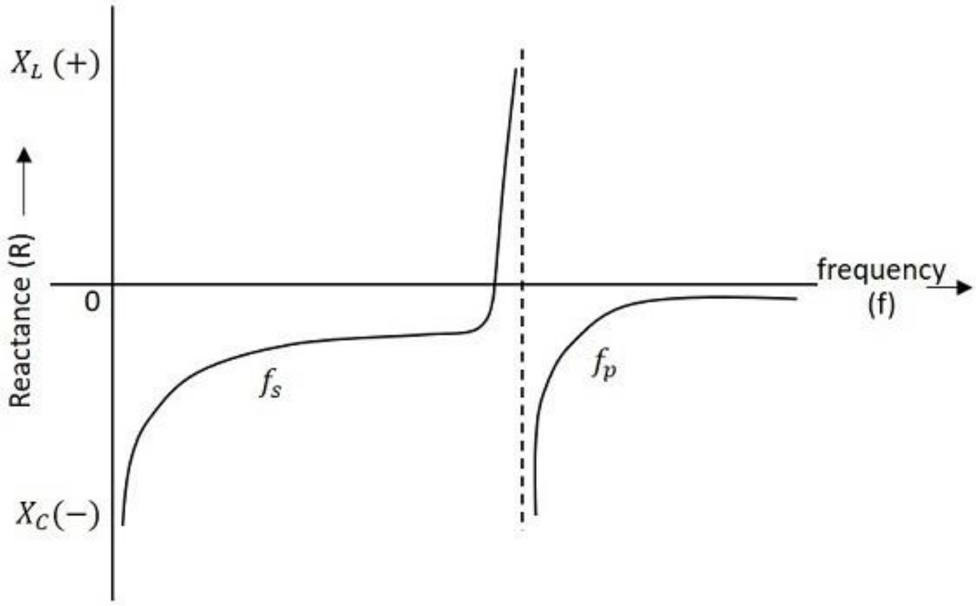
Symbol of a Crystal

Equivalent circuit of a crystal

The above equivalent circuit consists of a series R-L-C circuit in parallel with a capacitance C_m. When the crystal mounted across the AC source is not vibrating, it is equivalent to the capacitance C_m. When the crystal vibrates, it acts like a tuned R-L-C circuit.

Frequency response

The frequency response of a crystal is as shown below. The graph shows the reactance (X_L or X_C) versus frequency (f). It is evident that the crystal has two closely spaced resonant frequencies.



The first one is the series resonant frequency (f_s), which occurs when reactance of the inductance (L) is equal to the reactance of the capacitance C. In that case, the impedance of the equivalent circuit is equal to the resistance R and the frequency of oscillation is given by the relation,

$$f=1/2\pi\sqrt{LC}$$

The second one is the parallel resonant frequency (f_p), which occurs when the reactance of R-L-C branch is equal to the reactance of capacitor C_m. At this frequency, the crystal offers a very high impedance to the external circuit and the frequency of oscillation is given by the relation.

$$fp=1/2\pi\sqrt{(L.C_T)}$$

Where

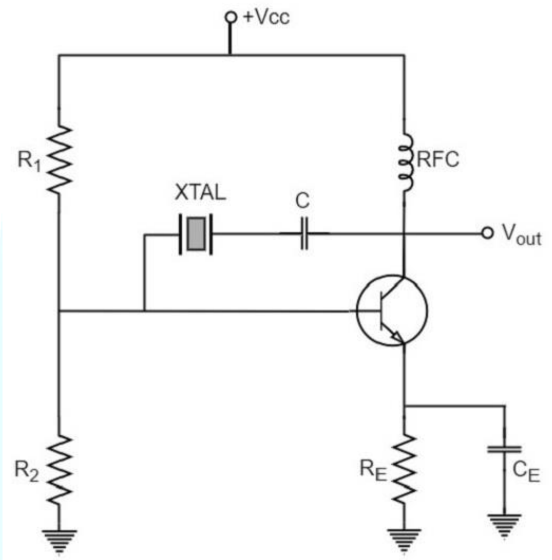
$$C_T=CCm/(C+Cm)$$

The value of C_m is usually very large as compared to C. Therefore, the value of C_T is approximately equal to C and hence the series resonant frequency is approximately equal to the parallel resonant frequency (i.e., $f_s = f_p$).

Crystal Oscillator Circuit

A crystal oscillator circuit can be constructed in a number of ways like a Crystal controlled tuned collector oscillator, a Colpitts crystal oscillator, a Clap crystal oscillator etc. But the **transistor pierce crystal oscillator** is the most commonly used one. This is the circuit which is normally referred as a crystal oscillator circuit.

The following circuit diagram shows the arrangement of a transistor pierce crystal oscillator.



In this circuit, the crystal is connected as a series element in the feedback path from collector to the base. The resistors R_1, R_2 and R_E provide a voltage-divider stabilized d.c. bias circuit. The capacitor C_E provides a.c. bypass of the emitter resistor and RFC (radio frequency choke) coil provides for d.c. bias while decoupling any a.c. signal on the power lines from affecting the output signal. The coupling capacitor C has negligible impedance at the circuit operating frequency. But it blocks any d.c. between collector and base.

The circuit frequency of oscillation is set by the series resonant frequency of the crystal and its value is given by the relation,

$f=1/2\pi\sqrt{LC}$

It may be noted that the changes in supply voltage, transistor device parameters etc. have no effect on the circuit operating frequency, which is held stabilized by the crystal.

Advantages

The advantages of crystal oscillator are as follows −

- They have a high order of frequency stability.
- The quality factor (Q) of the crystal is very high.

Disadvantages

The disadvantages of crystal oscillator are as follows –

- They are fragile and can be used in low power circuits.
- The frequency of oscillations cannot be changed appreciably.

Frequency Stability of an Oscillator

An Oscillator is expected to maintain its frequency for a longer duration without any variations, so as to have a smoother clear sinewave output for the circuit operation. Hence the term frequency stability really matters a lot, when it comes to oscillators, whether sinusoidal or non-sinusoidal.

The frequency stability of an oscillator is defined as the ability of the oscillator to maintain the required frequency constant over a long time interval as possible. Let us try to discuss the factors that affect this frequency stability.

Change in operating point

We have already come across the transistor parameters and learnt how important an operating point is. The stability of this operating point for the transistor being used in the circuit for amplification (BJT or FET), is of higher consideration.

The operating of the active device used is adjusted to be in the linear portion of its characteristics. This point is shifted due to temperature variations and hence the stability is affected.

Variation in temperature

The tank circuit in the oscillator circuit, contains various frequency determining components such as resistors, capacitors and inductors. All of their parameters are temperature dependent. Due to the change in temperature, their values get affected. This brings the change in frequency of the oscillator circuit.

Due to power supply

The variations in the supplied power will also affect the frequency. The power supply variations lead to the variations in V_{cc}. This will affect the frequency of the oscillations produced.

In order to avoid this, the regulated power supply system is implemented. This is in short called as RPS.

Change in output load

The variations in output resistance or output load also affects the frequency of the oscillator. When a load is connected, the effective resistance of the tank circuit is changed. As a result, the Q-factor of LC tuned circuit is changed. This results a change in output frequency of oscillator.

Changes in inter-element capacitances

Inter-element capacitances are the capacitances that develop in PN junction materials such as diodes and transistors. These are developed due to the charge present in them during their operation.

The inter element capacitors undergo change due to various reasons as temperature, voltage etc. This problem can be solved by connecting swamping capacitor across offending inter-element capacitor.

Value of Q

The value of Q (Quality factor) must be high in oscillators. The value of Q in tuned oscillators determines the selectivity. As this Q is directly proportional to the frequency stability of a tuned circuit, the value of Q should be maintained high.

Frequency stability can be mathematically represented as,

$S_w = d\theta/dw$

Where dθ is the phase shift introduced for a small frequency change in nominal frequency f_r. The circuit giving the larger value of (dθ/dw) has more stable oscillatory frequency.