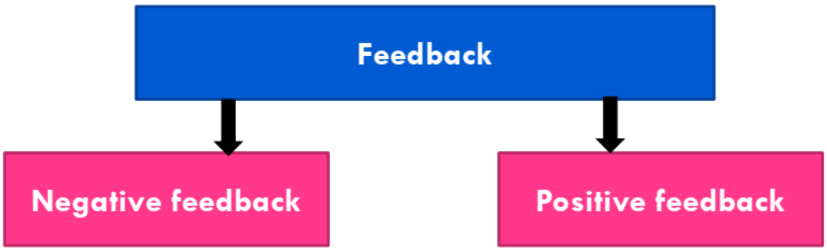
MODULE 3: FEEDBACK IN AMPLIFIERS AND OSCILLATORS

FEEDBACK IN AMPLIFIERS

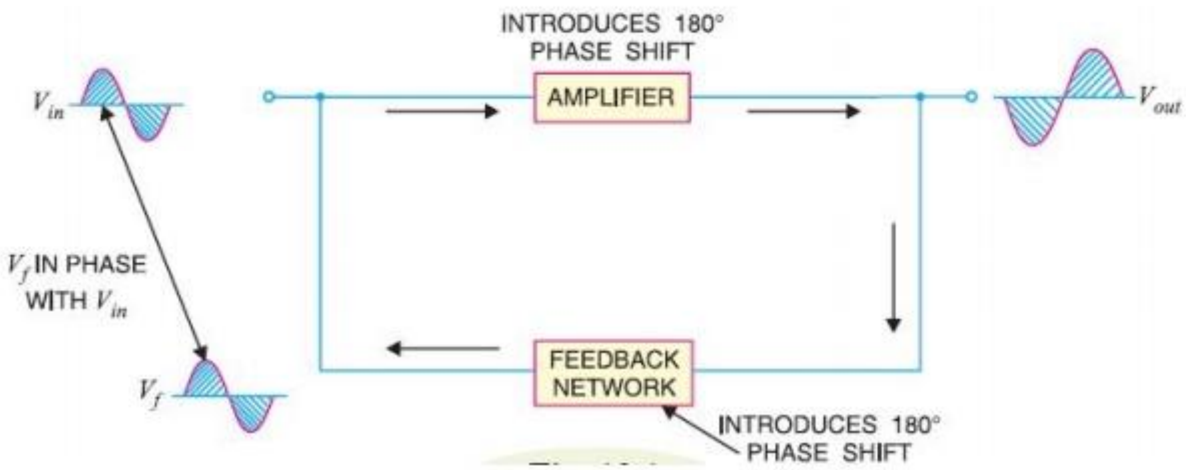
- The process of injecting a fraction of output energy of a device back to the input is known as feedback.
- Depending on whether feedback energy aids or opposes the input signal, feedback is classified into negative feedback and positive feedback



COMPARISON

	POSITIVE FEEDBACK	NEGATIVE FEEDBACK
1	The feedback signal is in phase with the input signal	The feedback signal is 180 degree out of phase with the input signal
2	Also called regenerative feedback	Also called degenerative feedback
3	It increases the net input to the amplifier Vi= Vs +Vf	It reduces the net input to the amplifier Vi= Vs - Vf
4	It increases the gain of the amplifier	It decreases the gain of the amplifier
5	It increases the noise & distortion	It decreases the noise & distortion
6	It decreases the stability of amplifier gain	It increases the stability of amplifier gain
7	It is used in oscillator circuits	It is used in amplifiers

POSITIVE FEEDBACK

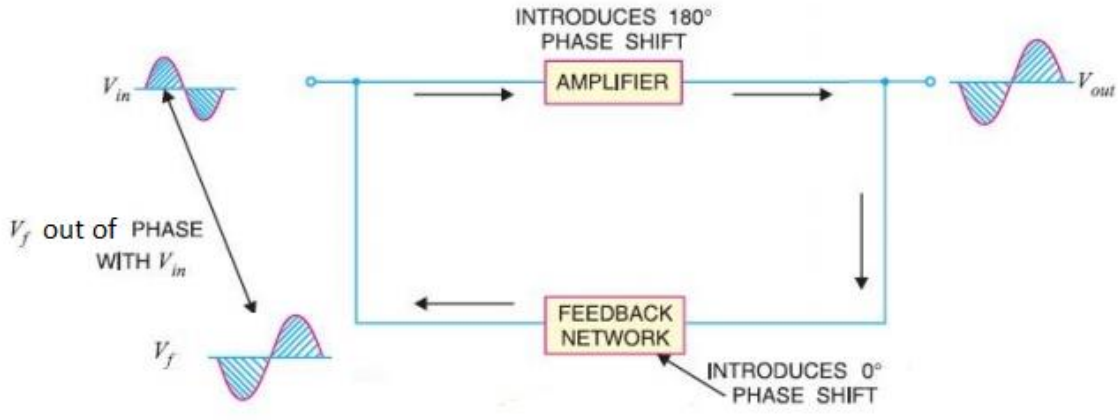


- When feedback energy(voltage/current) is **in phase** with the input signal and thus aids it,it is called positive feedback
- Both amplifier and feedback circuit introduce 180-degree phase shift. Thus a 360-degree phase shift around the loop is introduced.

- Feedback voltage V_f is in phase with input signal V_{in}
- Used in oscillators (device that converts dc power into ac power of any desired frequency)

NEGATIVE FEEDBACK

- When feedback energy(voltage/current) is **out of phase** with the input signal and thus opposes it, it is negative feedback.
- Amplifier circuit introduces 180-degree phase shift. Feedback network introduces no phase shift.
- Feedback voltage V_f is out of phase with input signal V_{in}



GAIN

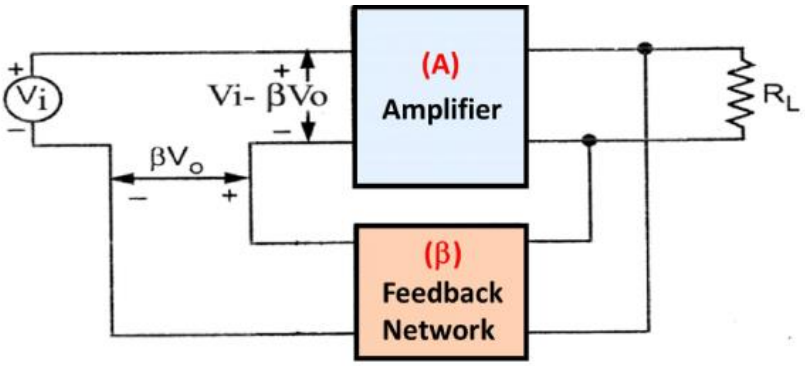


Fig above shows the block diagram of a basic feed back amplifier with negative feed back

Where:

A is the gain of the amplifier without feed back

β is the feed back factor

V_i is the input signal voltage

V_o is the output voltage

In this case actual input voltage to the amplifier. $= Vi - \beta Vo$

or $Vo = A(Vi - \beta Vo)$

$= AVi - A\beta Vo$

or $AVi = Vo + A\beta Vo$

$= Vo((1+A\beta)$

or $Vo = AVi/(1+A\beta)$

The gain of the feedback amplifier **Af** $= Vo/Vi$

$= (AVi/(1+A\beta))/Vi$

$= A_i/(1+A\beta)$

In case of positive feed back, gain **Af** $= A_i/(1-A\beta)$

From these expressions, It is seen that the gain of an amplifier decreases with negative feed back and increases with positive feed back.

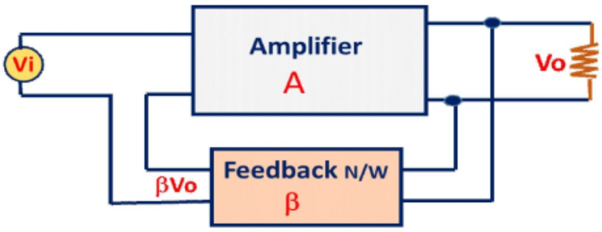
TYPES OF NEGATIVE FEEDBACK

Depending on the quantity chosen there are four basic types of feedback connections

1. Voltage series feedback
2. Voltage shunt feedback
3. Current series feedback
4. Current shunt feedback

1.Voltage series feed back

in this type of feedback a fraction of the out put voltage is applied in series with the input voltage through the feed back network. In this connection the input of the feed back network is in parallel with the out put of the amplifier and the output of the feedback network is in series to the input of the amplifier. This is also called shunt derived series fed feed back connection



The output resistance of the feedback amplifier

$$Ro^{I} = Ro/(1+A\beta)$$

Where β =feedback factor

Ro = Output resistance of the amplifier without feedback

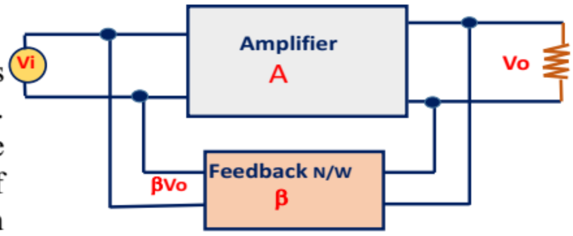
The input resistance of the feedback amplifier

$$Ri^{I} = (1+A\beta)\ Ri$$

Where Ri =Input resistance

2,Voltage shunt feedback

In voltage shunt feedback connection a fraction of the out put voltage is coupled back to the input voltage in parallel through feedback network. It is also called shunt derived shunt fed feedback connection. Here the feedback network is in parallel (shunt) to the both input and output of the amplifier. Therefore this type of feedback connection decreases both input and output resistances by a factor $1/(1+A\beta)$

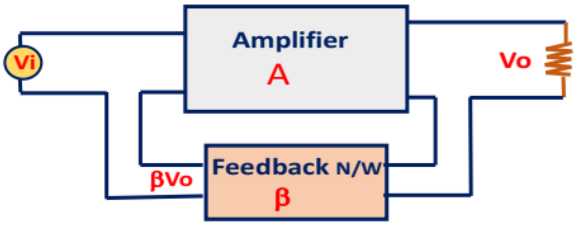


The output resistance $Ro^{I} = Ro/(1+A\beta)$

The input resistance $Ri^{I} = Ri/(1+A\beta)$

3.Current series feedback

In this type of feedback connection a fraction of the output current is converted in to a proportional voltage by the feedback network and then applied in series with the input. Here the input to the feedback network comes in series to the output of the amplifier and the output of the feedback networks comes in series to the input of the amplifier. Therefore both input and output impedances of the amplifier are increased due to feedback by a factor $(1+A\beta)$

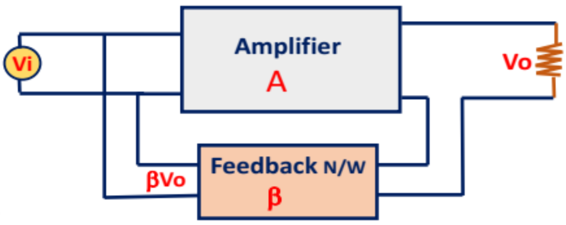


The output resistance $Ro^{I} = (1+A\beta)\ Ro$

The input resistance $Ri^{I} = (1+A\beta)\ Ri$

4.Current shunt feedback

In current shunt feedback connection a fraction of the out current is converted in to proportional voltage by the feedback network and then applied in parallel with the input voltage. In this case the output of feedback network shunts the input of the amplifier but its input is in series with the output of the amplifier. Hence this type of feedback connection decreases the input resistance by a factor $1/(1+A\beta)$And increases the output resistance by a factor $(1+A\beta)$



The output resistance $Ro^{I} = (1+A\beta)\ Ro$

The input resistance $Ri^{I} = Ri/(1+A\beta)$

Characteristics	Types of Feedback			
	Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
Voltage Gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Input resistance	Increases	Decreases	Increases	Decreases
Output resistance	Decreases	Decreases	Increases	Increases
Harmonic distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases

EFFECTS OF NEGATIVE FEEDBACK

Following are the effects of negative feedback on amplifier

1.Reduces the gain: Effect of negative feedback on the gain of the amplifier is that it reduces the gain by a factor 1/ (1+Aβ). This is the only disadvantage of the negative feedback.

***2.*Improves the Stability**

We have seen that the gain of amplifier with negative feed back

$$A_f = A/(1+A\beta)$$
$$\cong A/A\beta \quad (\text{Since } A\beta >>1)$$
$$= 1/\beta$$

Thus the gain of feed back amplifier is independent of the internal gain of the amplifier 'A' and the gain of the amplifier with feed back 'Af' depends only the feed back factor β' which in turn depends upon passive elements such as resistors. The value of passive elements remain fairly constant and hence the gain of the amplifier will be stable.

3.Reduces the distortion and noise

Since the gain of the amplifier is reduced by a factor **1/(1+Aβ)**. The distortin is also reducing in the same factor ie D_f=D/(1+Aβ)

4.Increases the input impedance and reduces the output impedance.

The expression for the input impedance in feedback amplifier is **Zinf= Z_{in} (1+Aβ)**

This equation shows that the input impedance of an amplifier with negative feedback is increased by a factor **(1+Aβ)**

The expression for output impedance in feedback amplifier is **Zof= Z_0 / (1+Aβ)**

Thus the output impedance of an amplifier with negative feedback is decreased by a factor **1/(1+Aβ)**

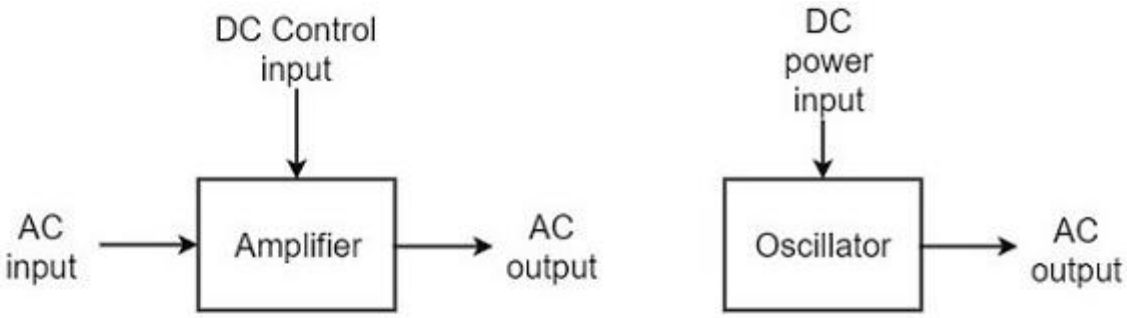
5.Improves frequency response and increases band width

When the gain of the amplifier falls by a factor **1/(1+Aβ)** with negative feedback thelower cut of frequency f_L is lowered by a factor**1/ (1+Aβ)** and the upper cutoff frequency $f_H$will be raised by the same factor. So bandwidth **f_H-f_L** will be increased.

OSCILLATORS

Amplifier vs. Oscillator

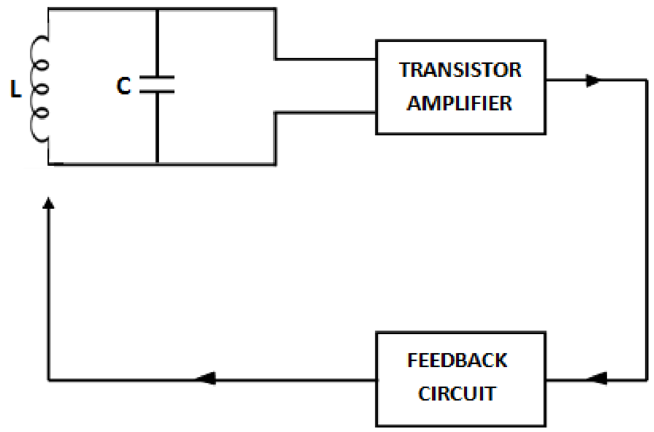
- An **amplifier** increases the signal strength of the input signal applied, where as an **oscillator** generates a signal without that input signal, but it requires dc for its operation.
- This is the main difference between an amplifier and an oscillator.
- It clearly shows how an amplifier takes energy from d.c. power source and converts it into a.c. energy at signal frequency.
- An oscillator produces an oscillating a.c. signal on its own.



Oscillators: ***A electronic circuit that generates an alternating voltage of desired frequency without requiring any externally applied input signal is called an oscillator***

PRACTICAL OSCILLATOR CIRCUIT

- A Practical Oscillator circuit consists of a tank circuit, a transistor amplifier, and a feedback circuit. The following circuit diagram shows the arrangement of a practical oscillator.



Tank Circuit

- The tank circuit consists of an inductance L connected in parallel with capacitor **C.**
- The values of these two components determine the frequency of the oscillator circuit and hence this is called as **Frequency determining circuit**.

Transistor Amplifier

- The output of the tank circuit is connected to the amplifier circuit so that the oscillations produced by the tank circuit are amplified here.
- Hence the output of these oscillations are increased by the amplifier.

Feedback Circuit

- The function of feedback circuit is to transfer a part of the output energy to LC circuit in proper phase.
- This feedback is positive in oscillators while negative in amplifiers.

Barkhausen's criterion for oscillations

1. The loop gain is equal to unity in absolute magnitude, that is,

   $|A\beta| = 1$

   Where
   - A is the voltage gain of amplifier without feedback
   - β is the feedback factor
2. Total phase shift around the closed loop should be 0 degree or 360 degrees

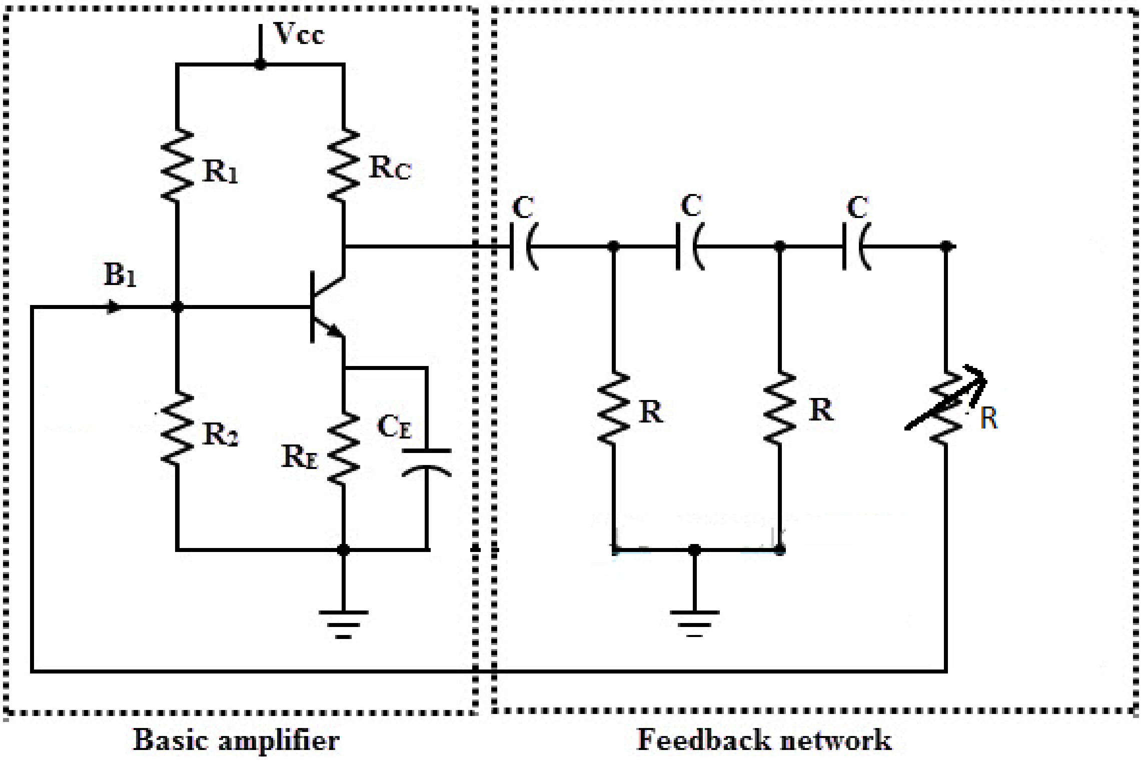
RC PHASE SHIFT OSCILLATOR

- The oscillator consists of a ***common emitter amplifier with a three stage RC network as feedback***.
- The value of resistors and capacitors of RC network and amplifiers are so chosen such that it satisfies Barkhausen Criterion.
- ***The CE amplifier provides 180-degree phase shift***.
- ***Each RC section provides a phase shift of 60°***
- ***Thus, a total 60° x 3 =180° phase shift is provided by RC phase shift feedback network***
- The circuit when switched ON the amplifier picks-up noises present in the circuit and gives to the RC network.
- ***Feedback factor β =1/29***
- For self-starting the oscillations, the loop gain should be slightly greater than 1so as to meet the losses A β > 1
- Amplifier gain A must be slightly greater than 29 for sustained oscillations
- When the circuit is switched ON, it produces oscillations of frequency **f_o**

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

where $R_1=R_2=R_3= R$

$C_1=C_2=C_3= C$



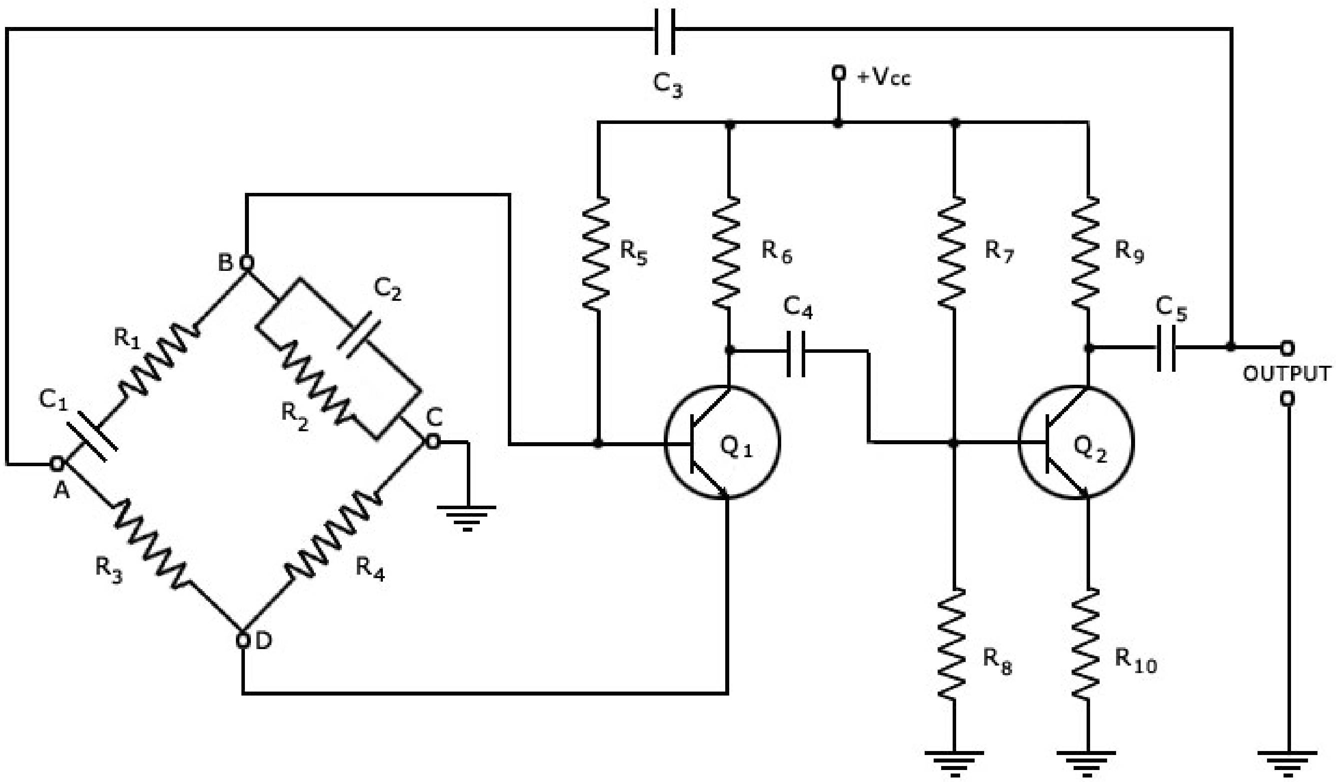
WEIN-BRIDGE OSCILLATOR

- Wien Bridge Oscillator is an oscillator which uses RC network to produce a **sine wave**.
- These are basically the **low-frequency oscillator** that generates audio and sub audio frequency that ranges between **20 Hz to 20 KHz**.
- ***The Wien bridge circuit that we use is a lead-lag network*** as with the rise in frequency phase shift lags and with the reduction in frequency, it leads.
- It gives highly stable oscillation frequency and does not vary much with supply or temperature variation.
- ***The two transistors produce a total phase shift of 360º*** so that proper positive feedback is ensured. The negative feedback in the circuit ensures constant output
- **Feedback factor β= 1/3**.
- Thus, in this case, voltage gain A, must be equal to or greater than 3, to sustain oscillations
- The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

- If $R_1 = R_2$ and $C_1 = C_2 = C$
  Then,

$$f = \frac{1}{2\pi RC}$$



HARTLEY OSCILLATOR

- A Hartley Oscillator (or RF oscillator) is a type of harmonic oscillator.
- ***The oscillation frequency for a Hartley Oscillator is determined by an LC tank circuit*** (i.e. a circuit consisting of capacitors and inductors).
- ***Hartley oscillators are typically tuned to produce waves in the radiofrequency band*** (which is why they are also known as RF oscillators).

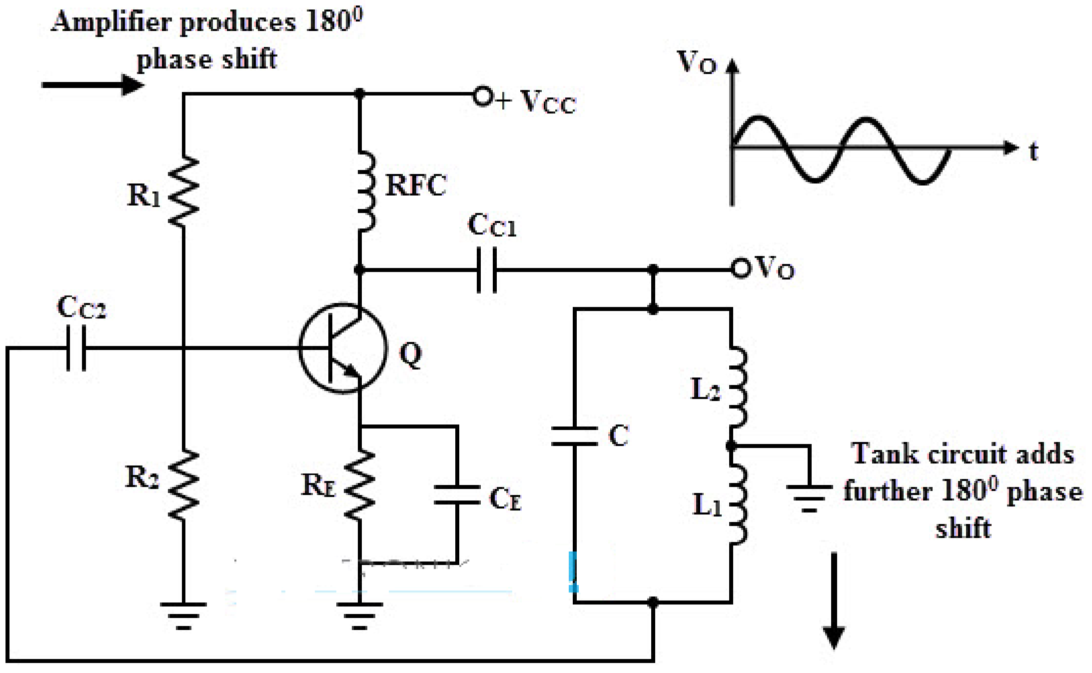
Construction

- Resistors R_1 and R_2 form the voltage divider bias network for the transistor in common-emitter CE configuration.
- Emitter resistor R_E forms the stabilizing network
- Capacitors C_i and C_o are the input and output decoupling capacitors
- Emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals.
- All these components are identical to those present in a common-emitter amplifier which is biased using a voltage divider network.
- ***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***.

Circuit Diagram



Working

- ***On switching ON the power supply, the transistor starts to conduct***, leading to an increase in the collector current, I_C which charges the capacitor C.
- On acquiring the maximum charge feasible, C starts to discharge via the inductors L_1 and L_2.
- These ***charging and discharging cycles in the tank circuit result in the damped oscillations.***
- The oscillation current in the tank circuit produces an AC ***voltage across the inductors L_1 and L_2 which are out of phase by 180^o*** as their point of contact are grounded.

- Further from the figure, it is evident that the ***output of the amplifier is applied across the inductor L_1 while the feedback voltage drawn across L_2*** is applied to the base of the transistor.
- We can conclude that the amplifier's output is in-phase with the tank circuit's voltage, while the energy fed back to the amplifier circuit will be out-of-phase by 180^o.
- The feedback voltage which is already 180^o out-of-phase with the ***transistor, is provided by an additional 180^o phase-shift due to the transistor action***.
- Hence the signal which appears at the transistor's output will be amplified and will have a ***net phase-shift of 360^o.***
- Feedback ratio given by

$$\beta = \frac{L_1}{L_2};\ if\ the\ coils\ are\ wound\ on\ different\ cores$$

- The frequency of such an oscillator is given as

$$F = \frac{1}{2\pi\sqrt{L_{eff}C}}$$

Where,

$$L_{eff}\ is\ the\ effective\ series\ inductance\ which\ is\ expressed\ as$$
$$L_{eff} = L_1 + L_2;\ if\ the\ coils\ are\ wound\ on\ different\ cores$$
$$L_{eff} = L_1 + L_2 + 2M;\ if\ the\ coils\ are\ wound\ on\ the\ same\ core$$

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 is a type of **LC oscillator**.
- ***The oscillation frequency for a Colpitts Oscillator is determined by an LC tank circuit*** (i.e. a circuit consisting of capacitors and inductors).

Construction

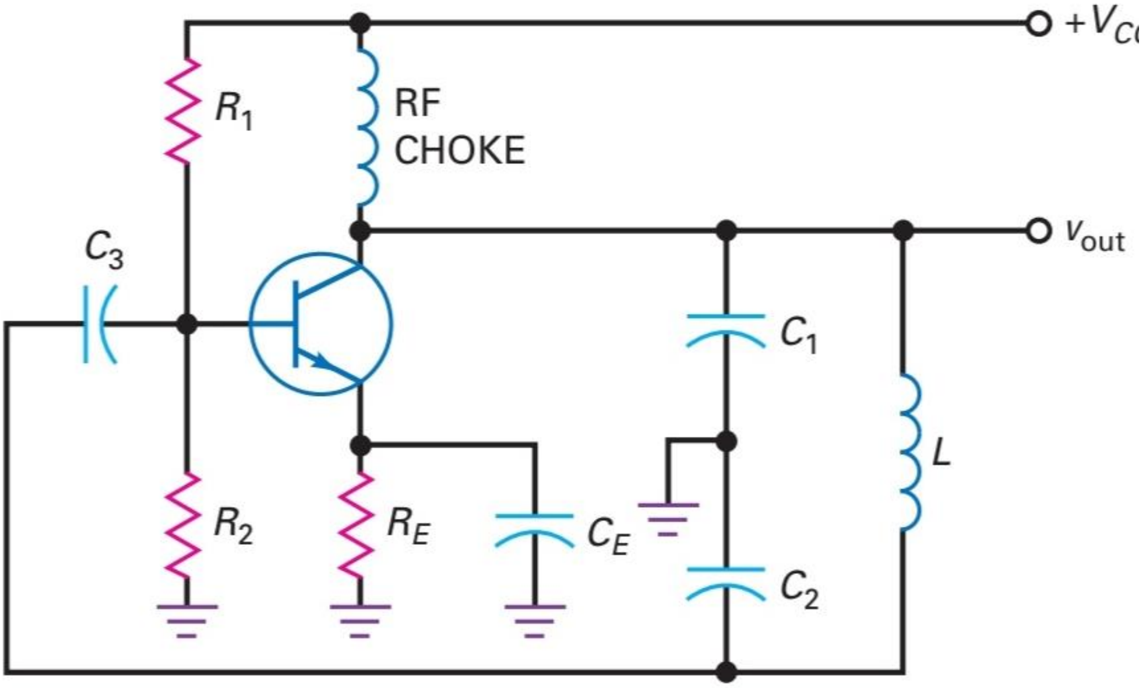
- Resistors R_1 and R_2 form the voltage divider bias network for the transistor in common-emitter CE configuration.
- Emitter resistor R_E forms the stabilizing network
- Capacitors C_i and C_o are the input and output decoupling capacitors
- Emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals.

- All these components are identical to those present in a common-emitter amplifier which is biased using a voltage divider network.
- ***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.

Circuit Diagram & Working



- ***As the power supply is switched ON, the transistor starts to conduct***, increasing the collector current I_C due to which the capacitors C_1 and C_2 get charged.
- On acquiring the maximum charge feasible, they start to discharge via the inductor L.
- During this process, the electrostatic energy stored in the capacitor gets converted into magnetic flux, which is stored within the inductor in the form of electromagnetic energy.
- Next, the inductor starts to discharge, which charges the capacitors once again. Likewise, the cycle continues, ***which gives rise to the oscillations in the tank circuit.***
- Further the figure shows that the output of the amplifier appears across C_1 and thus is in-phase with the tank circuit's voltage.
- On the other hand, the voltage feedback to the transistor is obtained across the capacitor C_2, which means the feedback signal is out-of-phase with the voltage at the transistor by 180^o.
- The ***voltages developed across the capacitors C_1 and C_2 are opposite in polarity*** as the point where they join is grounded.
- Further, this signal is provided with ***an additional phase-shift of 180^o by the transistor which results in a net phase-shift of 360^o around the loop***, satisfying the phase-shift criterion of Barkhausen principle.
- At this stage, the circuit can effectively act as an oscillator producing sustained oscillations by carefully monitoring the **feedback factor** given by

$$\beta = (C_1 / C_2).$$

❖ The frequency of such a **Colpitts Oscillator** depends on the components in its tank circuit and is given by

$$F = \frac{1}{2\pi\sqrt{LC_{eff}}}$$

Where the $\mathbf{C_{eff}}$ is the effective capacitance of the capacitors expressed as

$$\frac{C_1 C_2}{C_1 + C_2}$$

<u>Advantages</u>

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.

<u>Applications</u>

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**.

<u>CRYSTAL OSCILLATOR</u>

❖ 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**.

❖ The principle of crystal oscillators depends upon the **Piezo electric effect.**

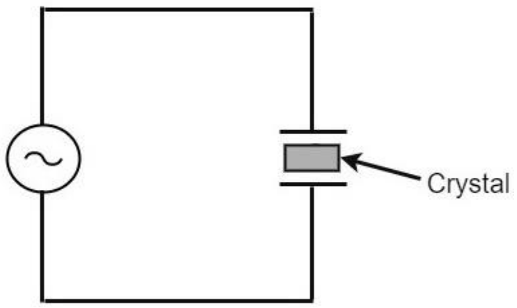
Piezo Electric Effect

❖ 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***.

Working of a Quartz Crystal

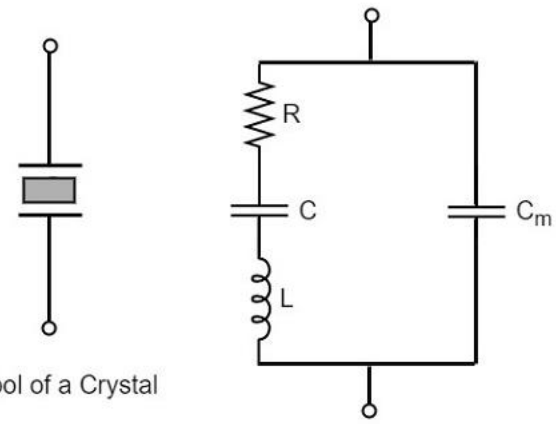
- In order to make a crystal work in an electronic circuit, the crystal is placed between two metal plates in the form of a capacitor.
- **Quartz** is the mostly used type of crystal because of its availability and strong nature while being inexpensive.
- The ac voltage is applied in parallel to the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

$$f = \frac{1}{2\pi\sqrt{L.C}}$$

- 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. A
- t this frequency, the crystal offers a very high impedance to the external circuit and the frequency of oscillation is given by the relation.

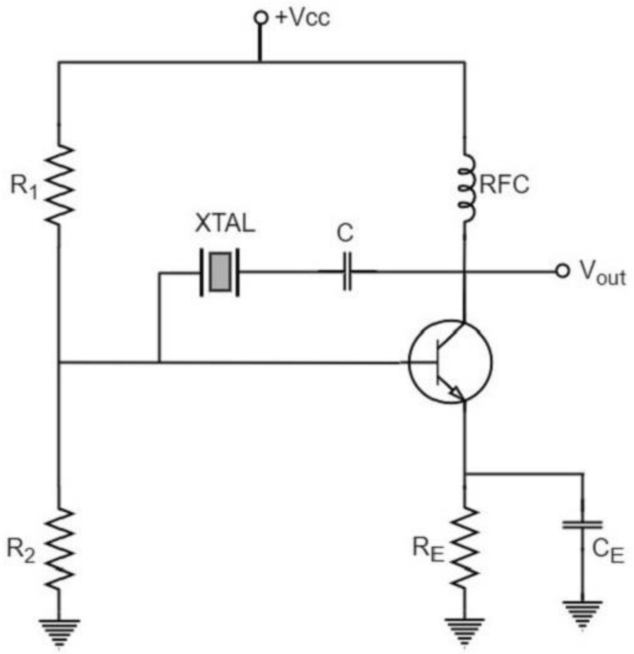
$$f_p = \frac{1}{2\pi\sqrt{L.C_T}}$$

Where

$$C_T = \frac{CC_m}{(C + C_m)}$$

- 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



- 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,
- 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.

$$f_o = \frac{1}{2\pi\sqrt{L.C}}$$

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.