OSCILLAOR

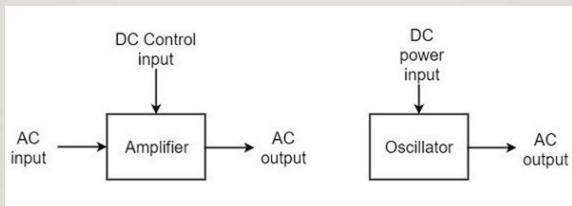
DR. SATISH CHANDRA

OSCILLATOR

- An oscillator generates output without any ac input signal.
- An electronic oscillator is a circuit which converts dc energy into ac at a very high frequency.
- An amplifier with a positive feedback can be understood as an oscillator.

AMPLIFIER VS. OSCILLATOR

- An amplifier increases the signal strength of the input signal applied, whereas 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.



AMPLIFIER VS. OSCILLATOR

- The frequency, waveform, and magnitude of a.c. power generated by an amplifier, is controlled by the a.c. signal voltage applied at the input, whereas those for an oscillator are controlled by the components in the circuit itself, which means no external controlling voltage is required.

CLASSIFICATION OF OSCILLATORS

- **Sinusoidal Oscillators** − The oscillators that produce an output having a sine waveform are called sinusoidal or harmonic oscillators. Such oscillators can provide output at frequencies ranging from 20 Hz to 1 GHz.
- **Non-sinusoidal Oscillators** − The oscillators that produce an output having a square, rectangular or saw-tooth waveform are called non-sinusoidal or relaxation oscillators. Such oscillators can provide output at frequencies ranging from 0 Hz to 20 MHz.

SINUSOIDAL OSCILLATORS

- **Tuned Circuit Oscillators** − These oscillators use a tuned-circuit consisting of inductors (L) and capacitors (C) and are used to generate high-frequency signals. Thus they are also known as radio frequency R.F. oscillators. Such oscillators are Hartley, Colpitts, Clapp-oscillators etc.
- **RC Oscillators** − There oscillators use resistors and capacitors and are used to generate low or audio-frequency signals. Thus they are also known as audio-frequency (A.F.) oscillators. Such oscillators are Phase –shift and Wein-bridge oscillators.

SINUSOIDAL OSCILLATORS

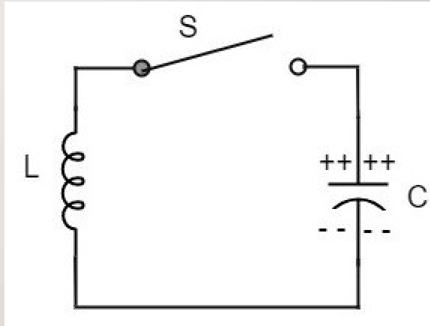
- **Crystal Oscillators** – These oscillators use quartz crystals and are used to generate highly stabilized output signal with frequencies up to 10 MHz. The Piezo oscillator is an example of a crystal oscillator.
- **Negative-resistance Oscillator** – These oscillators use negative-resistance characteristic of the devices such as tunnel devices. A tuned diode oscillator is an example of a negative-resistance oscillator.

THE OSCILLATORY CIRCUIT

- An oscillatory circuit produces electrical oscillations of a desired frequency. They are also known as tank circuits.
- A simple tank circuit comprises of an inductor L and a capacitor C both of which together determine the oscillatory frequency of the circuit.
- To understand the concept of oscillatory circuit, let us consider the following circuit.

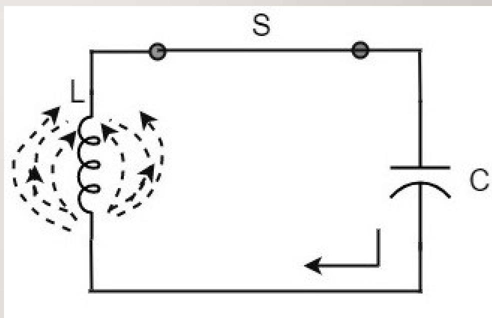
OSCILLATORY CIRCUIT

- The capacitor in this circuit is already charged using a dc source. In this situation, the upper plate of the capacitor has excess of electrons whereas the lower plate has deficit of electrons. The capacitor holds some electrostatic energy and there is a voltage across the capacitor.



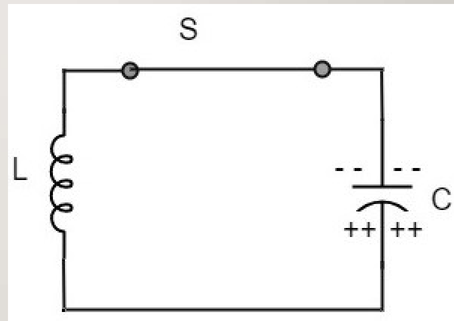
OSCILLATORY CIRCUIT

- When the switch **S** is closed, the capacitor discharges and the current flows through the inductor. Due to the inductive effect, the current builds up slowly towards a maximum value. Once the capacitor discharges completely, the magnetic field around the coil is maximum.



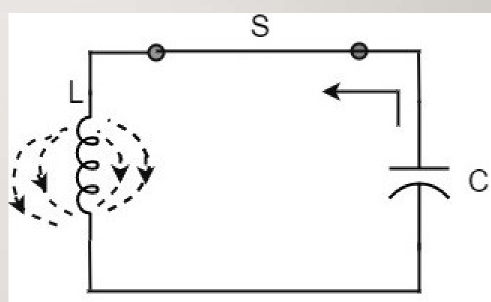
OSCILLATORY CIRCUIT

- Now, let us move on to the next stage. Once the capacitor is discharged completely, the magnetic field begins to collapse and produces a counter EMF according to Lenz's law. The capacitor is now charged with positive charge on the upper plate and negative charge on the lower plate.



OSCILLATORY CIRCUIT

- Once the capacitor is fully charged, it starts to discharge to build up a magnetic field around the coil, as shown in the following circuit diagram.



OSCILLATORY CIRCUIT

- This continuation of charging and discharging results in alternating motion of electrons or an oscillatory current. The interchange of energy between L and C produce continuous oscillations.
- In an ideal circuit, where there are no losses, the oscillations would continue indefinitely. In a practical tank circuit, there occur losses such as resistive and radiation losses in the coil and dielectric losses in the capacitor.
- These losses result in damped oscillations.

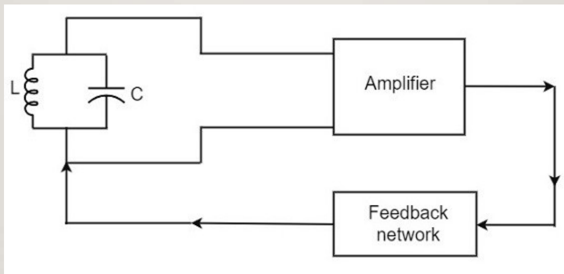
FREQUENCY OF OSCILLATIONS

- The frequency of the oscillations produced by the tank circuit are determined by the components of the tank circuit, the *L* and the *C*.
- The actual frequency of oscillations is the resonant frequency (or natural frequency) of the tank circuit which is given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

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.



PRACTICAL OSCILLATOR CIRCUIT

- **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.

FREQUENCY STABILITY OF AN OSCILLATOR

The change in oscillator frequency may arise due to the following factors;

- Operating point of the active device such as BJT or FET used should lie in the **linear region** of the amplifier. Its deviation will affect the oscillator frequency.
- The **temperature** dependency of the performance of circuit components affect the oscillator frequency.

FREQUENCY STABILITY OF AN OSCILLATOR

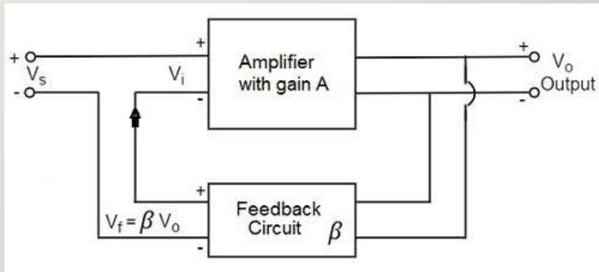
The change in oscillator frequency may arise due to the following factors

- The changes in **DC supply voltage** applied to the active device, shift the oscillator frequency. This can be avoided if a regulated power supply is used.
- A change in **output load** may cause a change in the Q-factor of the tank circuit, thereby causing a change in oscillator output frequency.
- The presence of inter element capacitances and **stray capacitances** affect the oscillator output frequency and thus frequency stability.

PRINCIPLE OF FEEDBACK AMPLIFIER

- A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors. The concept of feedback amplifier can be understood from the following figure.

$$A = \frac{V_o}{V_i}$$



PRINCIPLE OF FEEDBACK AMPLIFIER

- From the figure, the gain of the amplifier is represented as *A*. The gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i.
- The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier. The quantity $\beta = V_f / V_o$ is called as **feedback ratio** or feedback fraction.
- This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s. Now,

$$V_i = V_s + V_f = V_s + \beta V_o$$

$$V_i = V_s - V_f = V_s - \beta V_o$$

PRINCIPLE OF FEEDBACK AMPLIFIER

- Let us consider the case of **negative feedback**. The output V_o must be equal to the input voltage (V_s - βV_o) multiplied by the gain A of the amplifier.
- Hence, $$(V_s - \beta V_o)A = V_o$$
- or, $$AV_s - A\beta V_o = V_o$$
- or, $$AV_s = V_o(1 + \beta A)$$
- Therefore, $$\frac{V_o}{V_S} = \frac{A}{1 + \beta A}$$

PRINCIPLE OF FEEDBACK AMPLIFIER

- Let A_f be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e.,

$$A_f = \frac{Output\ voltage}{Input\ signal\ voltage} = \frac{V_o}{V_s}$$

$$\frac{V_o}{V_S} = \frac{A}{1 + \beta A}$$

- So, from the above two equations, we can understand that,

PRINCIPLE OF FEEDBACK AMPLIFIER

- The equation of gain of the feedback amplifier, with **negative feedback** is given by

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

- The equation of gain of the feedback amplifier, with **positive feedback** is given by

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

- These are the standard equations to calculate the gain of feedback amplifiers.

BARKHAUSEN CRITERION

- The βA is the feedback factor or the loop gain. If $\beta A = 1$, $A_f = \infty$.
- Thus the gain becomes infinity, i.e., there is output without any input.
- In another words, the amplifier works as an Oscillator.
- The condition $A\beta = 1$ is called as **Barkhausen Criterion** of oscillations.

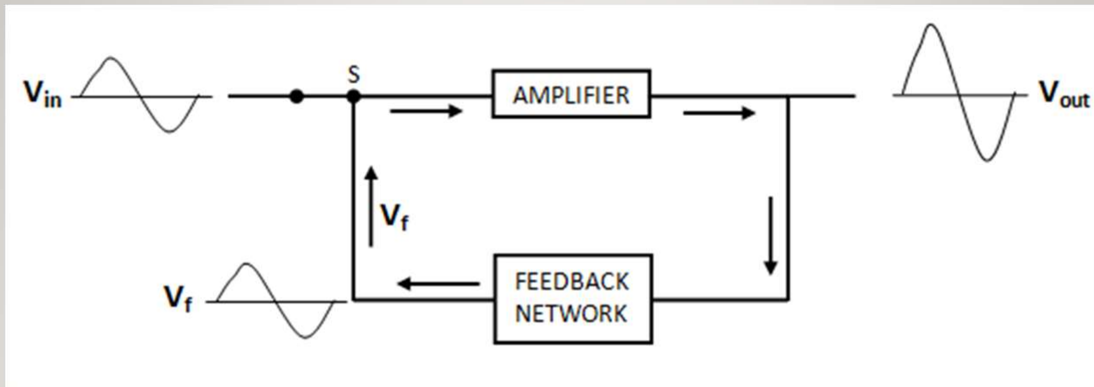
TYPES OF FEEDBACKS

- The process of injecting a fraction of output energy of some device back to the input is known as **Feedback**.
- It has been found that feedback is very useful in reducing noise and making the amplifier operation stable.
- Depending upon whether the feedback signal aids or opposes the input signal, there are two types of feedbacks used.
  - Positive Feedback
  - Negative Feedback

POSITIVE FEEDBACK

- The feedback in which the feedback energy i.e., either voltage or current is in phase with the input signal and thus aids it is called as **Positive feedback**.
- Both the input signal and feedback signal introduces a phase shift of 180^o thus making a 360^o resultant phase shift around the loop, to be finally in phase with the input signal.

POSITIVE FEEDBACK



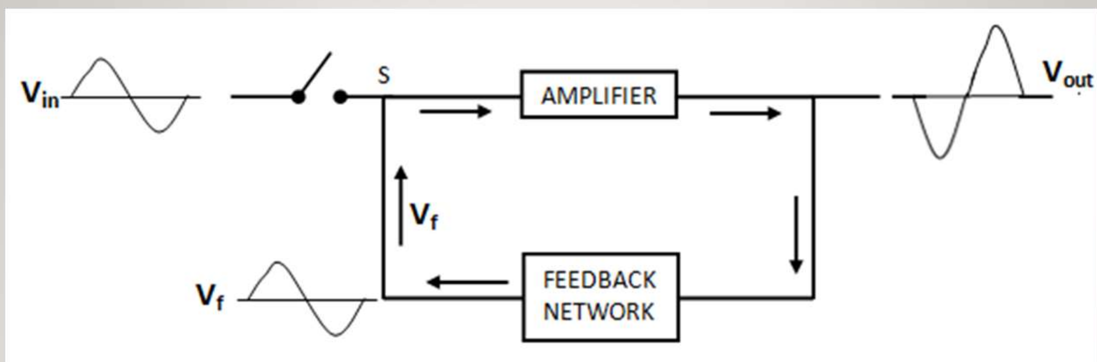
POSITIVE FEEDBACK

- Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as
  - Increasing distortion
  - Instability
- It is because of these disadvantages the positive feedback is not recommended for the amplifiers.
- If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed.

NEGATIVE FEEDBACK

- The feedback in which the feedback energy i.e., either voltage or current is out of phase with the input and thus opposes it, is called as **negative feedback**.
- In negative feedback, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it produces no phase shift or zero phase shift.
- Thus the resultant feedback voltage V_f is 180° out of phase with the input signal V_{in}.

NEGATIVE FEEDBACK



NEGATIVE FEEDBACK

- Though the **gain** of negative feedback amplifier is **reduced**, there are many advantages of negative feedback such as
  - Stability of gain is improved
  - Reduction in distortion
  - Reduction in noise
  - Increase in input impedance
  - Decrease in output impedance
  - Increase in the range of uniform application
- It is because of these advantages negative feedback is frequently employed in amplifiers.

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.

TUNED 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.

TUNED CIRCUIT OSCILLATORS

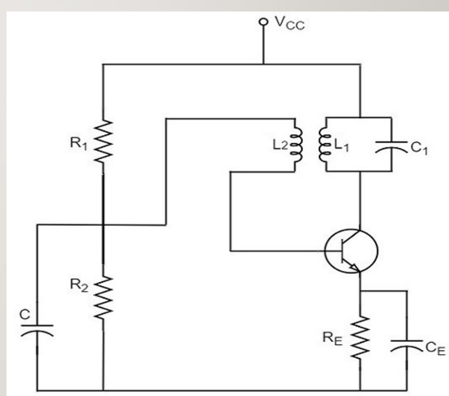
- Depending upon the way the feedback is used in the circuit, the LC oscillators are divided as the following types.
- **Tuned-collector or Armstrong Oscillator** − It uses inductive feedback from the collector of a transistor to the base. The LC circuit is in the collector circuit of the transistor.
- **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 OSCILLATORS

- 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.
- The following circuit diagram shows the arrangement of a tuned collector circuit.

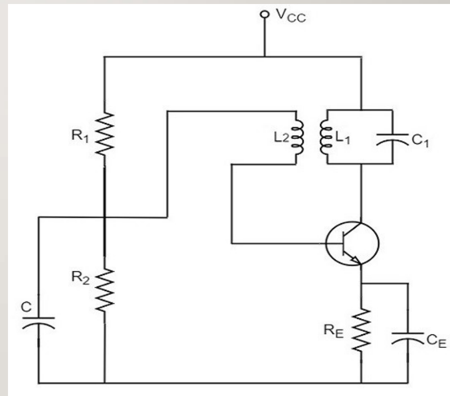
CONSTRUCTION

- The resistors R_1, R_2 and R_E are used to provide DC bias to the transistor. The capacitors C_E and C are the by-pass capacitors.
- The secondary of the transformer provides AC feedback voltage that appears across the base-emitter junction of R_1 and R_2 is at AC ground due to by-pass capacitor C.



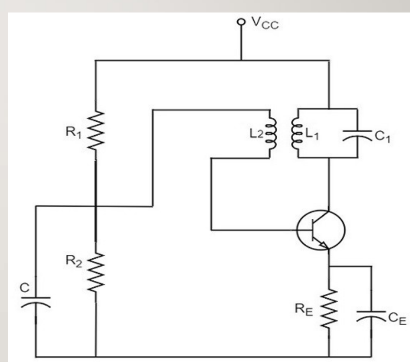
CONSTRUCTION

- 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.



CONSTRUCTION

- 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.



OPERATION

- Once the supply is given, the collector current starts increasing and charging of capacitor C_1 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.

OPERATION

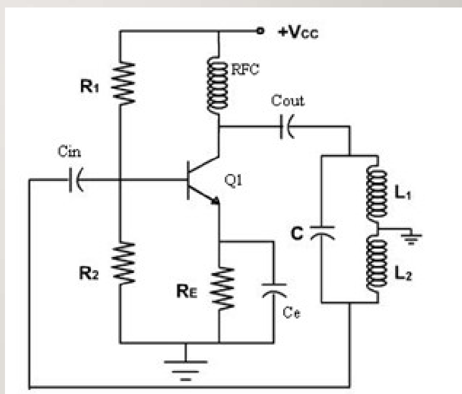
- The frequency of voltage induced in the secondary winding is same as that of the tank circuit and its magnitude depends upon the number of turns in secondary winding and coupling between both the windings.
- The voltage across L_2 is applied between base and emitter and appears in the amplified form in the collector circuit, thus overcoming the losses in the tank circuit.

OPERATION

- 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.

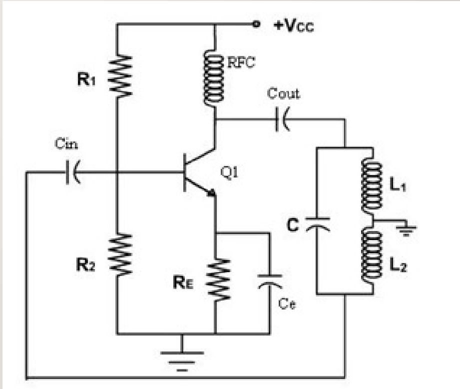
HARTLEY OSCILLATOR

- A very popular local oscillator circuit that is mostly used in radio receivers is the Hartley Oscillator circuit.
- Hartley Oscillator was invented in 1915 by the American engineer **Ralph Hartley**.



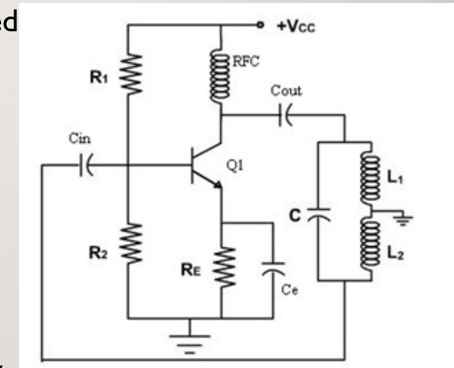
CONSTRUCTION

- 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.



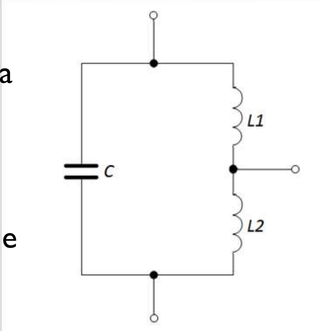
CONSTRUCTION

- The capacitors C_{out} and C_{in} are employed to block d.c. and to provide an a.c. path.
- The radio frequency choke (RFC) 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

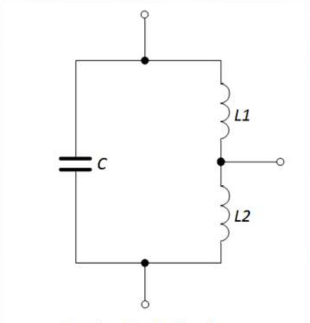
- The frequency determining network is a parallel resonant circuit which consists of the inductors L_1 and L_2 along with a variable capacitor C.
- The junction of L_1 and L_2 are earthed.
- The coil L_2 has its one end connected to base via C_{in} and the other to emitter via C_e.
- So, L_2 is in the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



Hartley Tank Circuit

OPERATION

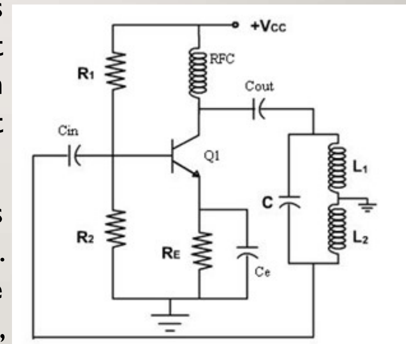
- When the collector supply is given, a transient current is produced in the oscillatory or tank circuit. The oscillatory current in the tank circuit produces a.c. voltage across L_1.
- The **auto-transformer** made by the inductive coupling of L_1 and L_2 helps in determining the frequency and establishes the feedback.



Hartley Tank Circuit

OPERATION

- 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

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

$$L_T = L_1 + L_2 + 2M$$

- Here, L_T is the total cumulatively coupled inductance; L_I and L_2 represent inductances of Ist 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.

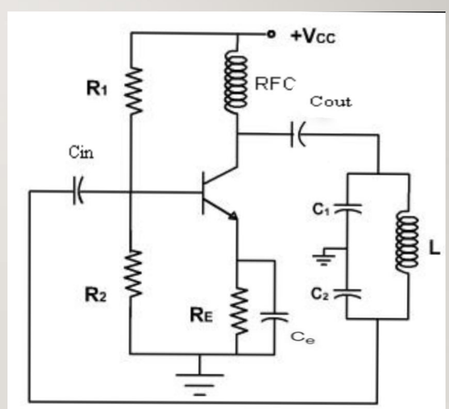
APPLICATIONS

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.

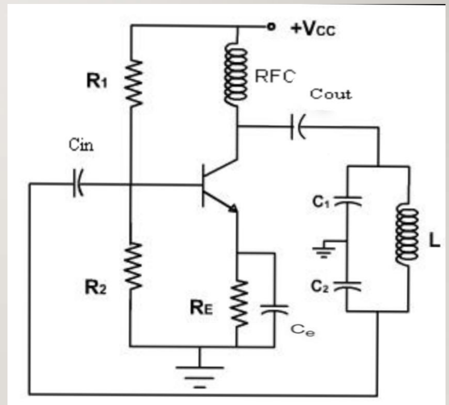
COLPITTS OSCILLATOR

- A Colpitts oscillator looks just like the Hartley oscillator but the inductors and capacitors are replaced with each other in the tank circuit.
- Colpitts oscillator is designed by and named after an American engineer **Edwin H Colpitts** in 1918.



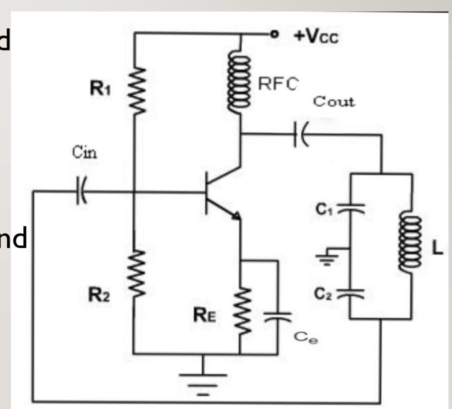
CONSTRUCTION

- 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.



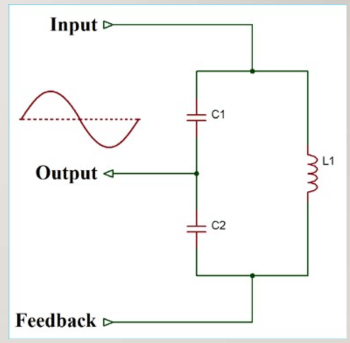
CONSTRUCTION

- The capacitors C_{out} and C_{in} 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.



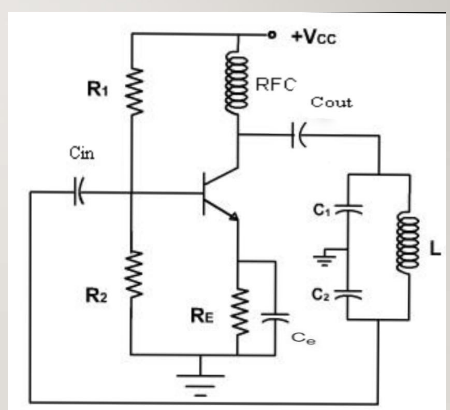
TANK CIRCUIT

- 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_2 has its one end connected to base via C_{in} and the other to emitter via C_e.
- The voltage developed across C_2 provides the regenerative feedback required for the sustained oscillations.



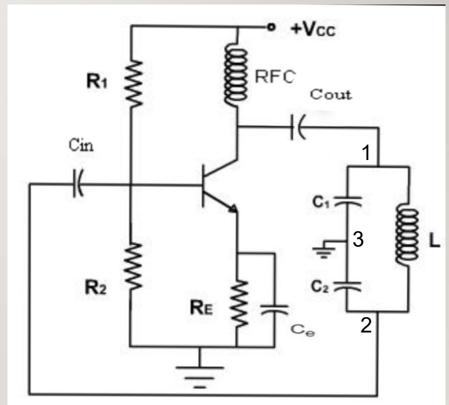
OPERATION

- 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.



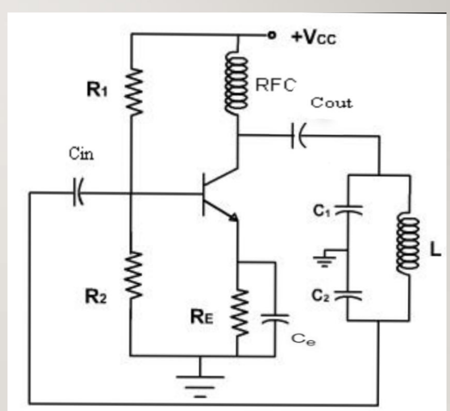
OPERATION

- 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°.



OPERATION

- 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

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

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

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

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

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.

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.