UNIT II OSCILLATORS

Barkhausen criterion for oscillation - Phase shift, Wien bridge - Hartley and Colpitts oscillators - Clapp oscillator - Ring oscillators and crystal oscillators - Oscillator amplitude stabilization.

2.3.Types of Oscillators:

- There are many types of oscillators, but can broadly be classified into two main categories
- Harmonic Oscillators (also known as Linear Oscillators) and
- Relaxation Oscillators.
- In a harmonic oscillator, the energy flow is always from the active components to the passive components and the frequency of oscillations is decided by the feedback path.
- Whereas in a relaxation oscillator, the energy is exchanged between the active and the passive components and the frequency of oscillations is determined by the charging and discharging time-constants involved in the process.
- Further, harmonic oscillators produce low-distorted sine-wave outputs
- while the relaxation oscillators generate non-sinusoidal (saw- tooth, triangular or square) wave-forms. Sinusoidal or non-sinusoidal.

- An oscillator generating square wave or a pulse train is called multivibrator :

  1. Bistable multivibrator (Flip-Flop Circuit).
  2. Monostable multivibrator.
  3. Astable multivibrator (Free-running).

- Depending upon type of feedback, we have

  1. Tuned Circuit (LC) oscillators.
  2. RC oscillators, and
  3. Crystal oscillators.

The main types of Oscillators include:

1. RC Oscillators
   - i. Wien Bridge Oscillator
   - ii. RC Phase Shift Oscillator

2. LC Oscillators
    1. Hartley Oscillator
    2. Colpitts Oscillator
    3. Clapp Oscillator
3. Crystal Oscillators

2.3.1 LC- Oscillators:

LC Oscillator	Z1	Z2	Z3
Hartley Oscillator	L	L	C
Colpitts Oscillator	C	C	L
Clapp Oscillator	C	C	L-C

2.3.2 Hartley oscillators

- Hartley Oscillator is a type of harmonic oscillator which was invented by Ralph Hartley in 1915. These are the Tuned Circuit Oscillators which are used to produce the waves in the range of radio frequency and hence are also referred to as RF Oscillators. Its frequency of oscillation is decided by its tank circuit which has a capacitor connected in parallel with the two serially connected inductors, as shown by Figure 1.

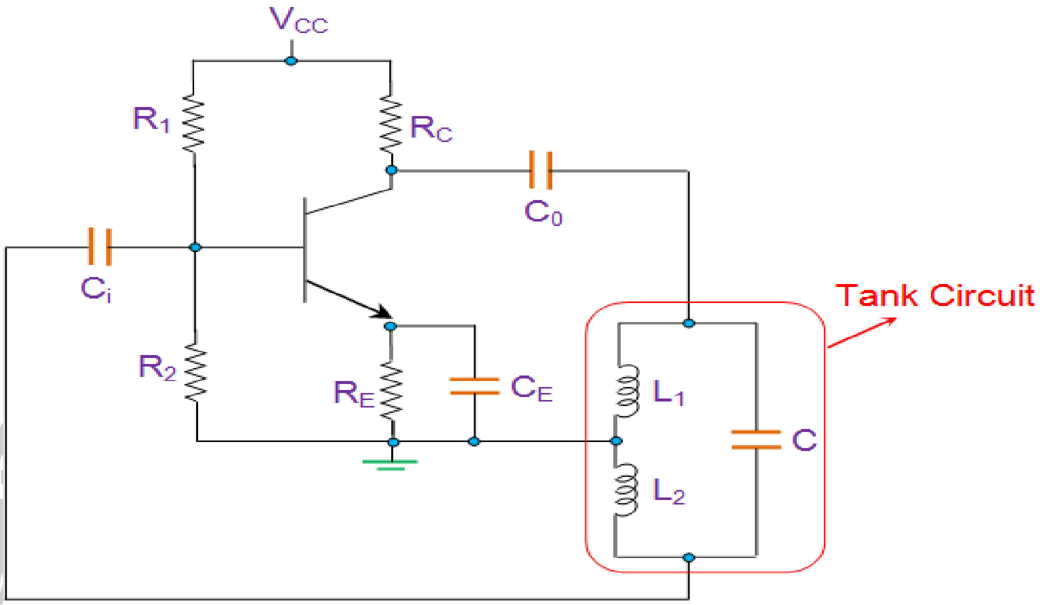


Figure 1 Hartley Oscillator

- Note that in the collector-tuned circuit, two inductor coils are used.
- One end of these coils is grounded.
- If we make the tickler coil an integral part of the circuit, we get Hartley Oscillator.
- When the tank circuit resonates, the circulating current flows through L_1 in series with L_2. Hence the equivalent inductance is
- O/p current is collector current $h_{fe}I_b$
- h_{ie} is the input impedance of the transistor. output of the feedback is current I_b which is input of transistor .
- Now change current source to voltage source
- $V_0 = h_{fe} I_b X_{L2} = h_{fe} I_b jwL_2$ ------ (1)
- L_1 and h_{ie} parallel

$$I = \frac{-V_0}{[X_{L2} + X_C] + [X_{L1} \,||\, h_{ie}]} \quad \text{------ (2)}$$

$$X_{L2} + X_C = jwL_2 + \frac{1}{jwC}$$

$$I = \frac{-h_{fe} I_b jwL_2}{jwL_2 + \frac{1}{jwC} + \frac{jwL_1 h_{ie}}{(jwL_1 + h_{ie})}} \quad \text{------ (3)}$$

Imaginary part of R.H.S must be zero

$$W^3 h_{fe} L_1 L_2 C [h_{ie} - w^2 h_{ie} C (L_1 + L_2)] = 0$$

$$w = \frac{1}{\sqrt{C(L_1 + L_2)}}$$

$$L = L_1 + L_2 \Rightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$$

The feedback factor is $\beta = \frac{L_2}{L_1}$

- Here the R_C is the collector resistor while the emitter resistor R_E forms the stabilizing network. Further the resistors R_1 and R_2 form the voltage divider bias network for the transistor in common-emitter CE configuration.
- Next, the capacitors C_i and C_o are the input and output decoupling capacitors while the emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals. All these components are identical to those present in the case of a common-emitter amplifier which is biased using a voltage divider network.
- However, Figure 1 also shows one more set of components viz., the inductors L_1 and L_2 and the capacitor C which form the tank circuit (shown in red enclosure).
- 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.
- This charging and discharging cycles result in the damped oscillations in the tank circuit. 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° as their point of contact is 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.
- Thus one can conclude that the output of the amplifier is in- phase with the tank circuit's voltage and supplies back the energy lost by it while the energy fed back to amplifier circuit will be out-of-phase by 180°.
- The feedback voltage which is already 180° out-of-phase with the transistor is provided by an additional 180° 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°.

At this state, if one makes the gain of the circuit to be slightly greater than the feedback ratio given by

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

$$\beta = \frac{L_1 + M}{L_2 + M}$$

(if the coils are wound on the same core with M indicating the mutual inductance)

- Then the circuit generates the oscillations which can be sustained by maintaining the gain of the circuit to be equal to that of the feedback ratio. This causes the circuit in Figure 1 to act as an oscillator as it would then satisfy both the conditions of the Barkhausen criteria.
- The frequency of such an oscillator is given as

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

- Hartley oscillators are available in many different configurations including series-or shunt-fed, common-emitter or common-base configured, and BJT (Bipolar Junction Transistor) or FET (Field Effect Transistor) amplifier based. Further it is to be noted that the transistor-based amplifier section of Figure 1 can even be replaced by an amplifier of any other kind like that of an inverting amplifier formed by an Op-Amp as shown by Figure 2.
- The working of this kind of oscillator is similar to that of the one shown earlier. However, here, the gain of the oscillator can be individually adjusted using the feedback resistor R_f due to the fact that the gain of the inverting amplifier is given as $-R_f / R_1$.
- From this, it can be noted that, in this case, the gain of the circuit is less dependent on the circuit elements of the tank circuit.
- This increases the stability of the oscillator in terms of its frequency.

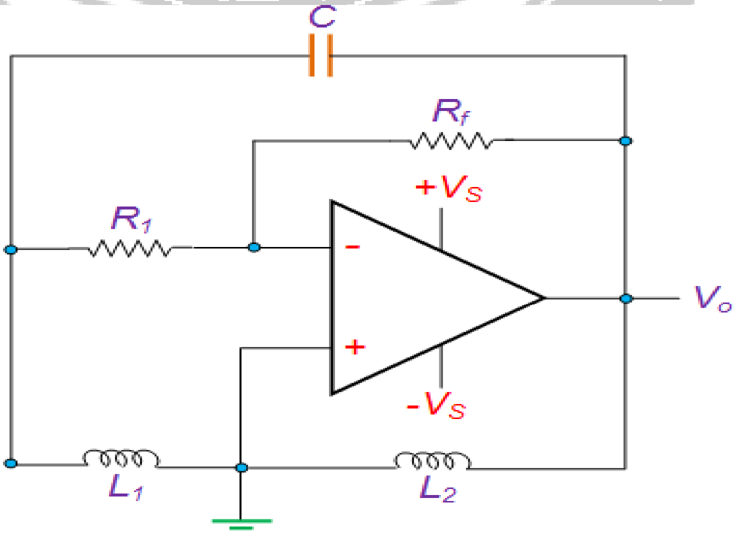


Figure 2 Hartley Oscillator Using an Op-Amp

- Hartley Oscillators are advantageous as they are easy-tunable circuits with a very few components including a capacitor and either two inductors or a tapped coil.
- This results in a constant amplitude output throughout its wide operational frequency range which typically ranges from 20 KHz to 30 MHz.

- However, this kind of oscillator is not suitable for low frequency as it would result in a large-sized inductor which makes the circuit bulky.
- Further, the output of Hartley Oscillator has high content of harmonics in it and hence does not suit for the applications which require pure sine wave.

2.3.3Colpitts oscillators

- Colpitts Oscillator is a type of LC oscillator which falls under the category of Harmonic Oscillator and was invented by Edwin Colpitts in 1918.
- Figure 1 shows a typical Colpitts oscillator with a tank circuit in which an inductor L is connected in parallel to the serial combination of capacitors C_1 and C_2 (shown by the red enclosure).

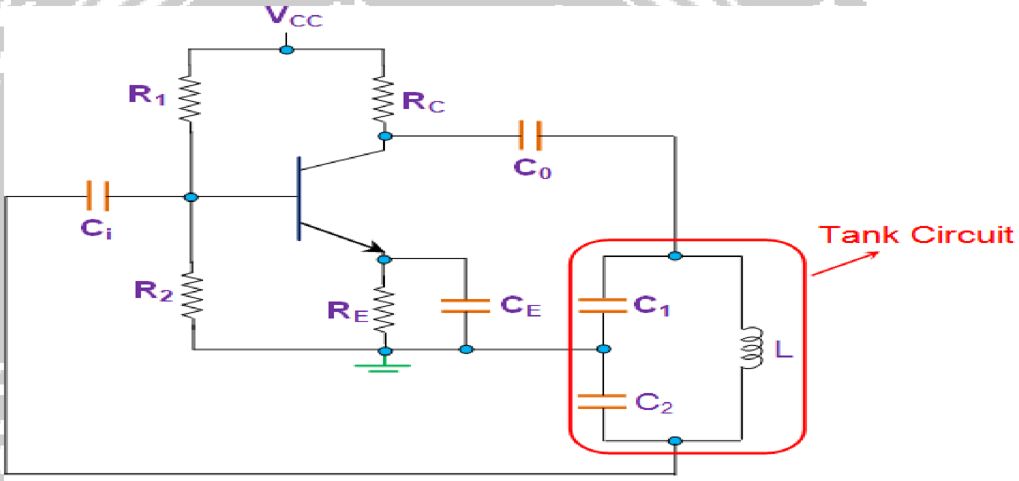
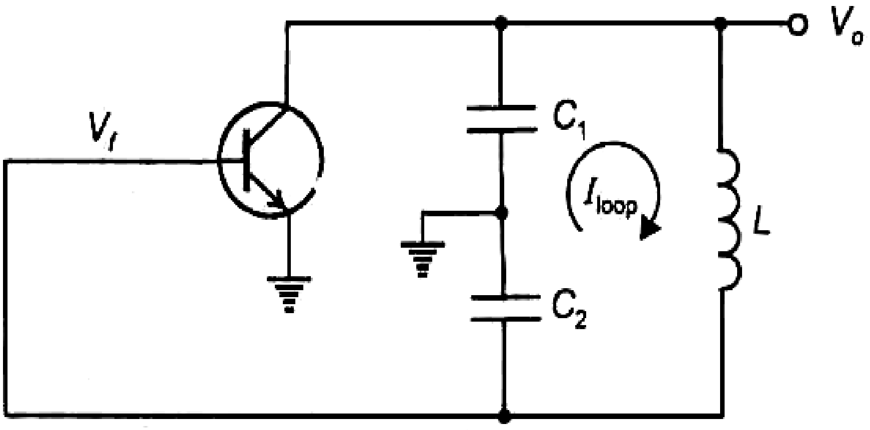


Figure 1 Colpitts Oscillator



- An excellent circuit.
- Widely used in commercial signal generators.
- Uses two capacitors instead of the inductive voltage divider.

$$C = \frac{C_1 C_2}{C_1 + C_2} \qquad \beta = \frac{1/\omega C_2}{1/\omega C_1} = \frac{C_1}{C_2}$$

Other components in the circuit are the same as that found in the case of common-emitter CE which is biased using a voltage divider network i.e. R_C is the collector resistor, R_E is the emitter resistor which is used to stabilize the circuit and the resistors R_1 and R_2 form the voltage divider bias network.

- Further, the capacitors C_i and C_o are the input and output decoupling capacitors while the emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals.

Here, 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 in turn 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 and makes-up for the energy lost by re-supplying it. On the other hand, the voltage feedback to the transistor is the one obtained across the capacitor C_2, which means the feedback signal is out-of-phase with the voltage at the transistor by 180^o. This is due to the fact that 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 state, the circuit can effectively act as an oscillator producing sustained oscillations by carefully monitoring the feedback ratio given by (C_1 / C_2). The frequency of such a Colpitts Oscillator depends on the components in its tank circuit and is given by

- O/p current is collector current $h_{fe}I_b$
- h_{ie} is the input impedance of the transistor. output of the feedback is current I_b which is input of transistor .
- Now change current source to voltage source
- $V_0 = h_{fe} I_b X_{C2} = h_{fe} I_b (1/jwC_2)$----- (1)

$$I = \frac{-V_O}{[X_{C2} + X_L] + [X_{C1} \,||\, h_{ie}]} \quad \text{------ (2)}$$

$$X_{C2} + X_L = jwL + \frac{1}{jwC_2} \qquad X_{C1} \,||\, h_{ie} = \frac{(1/jwC_1)\, h_{ie}}{((1/jwC_1) + h_{ie})}$$

$$I_b = I \times \frac{XC_1}{XC_1 + h_{ie}} \quad \text{------ (4)}$$

Imaginary part of R.H.S must be zero

$w\, h_{ie}\, [C_1 + C_2 – w^2LC_1C_2] = 0$

$$w = \frac{1}{\sqrt{L(C_1C_2 \;/\; C_1+C_2)}}$$

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

Where, the C_{eff} is the effective capacitance of the capacitors expressed as $\dfrac{C_1C_2}{C_1 + C_2}$

As a result, these oscillators can be tuned either by varying their inductance or the capacitance. However the variation of L does not yield a smooth variation. Hence they are usually tuned by varying the capacitances which are generally ganged, due to which a change in any one of them changes both of them. Nevertheless, the process is tedious and requires special large- valued capacitor. Thus, the Colpitts oscillators are seldom preferred in the applications where in the frequency varies but are more popular as fixed frequency oscillators due to their simple design. Further they offer better stability in comparison with the Hartley Oscillators as they are exempted from the mutual inductance effect present in-between the two inductors of the latter case.

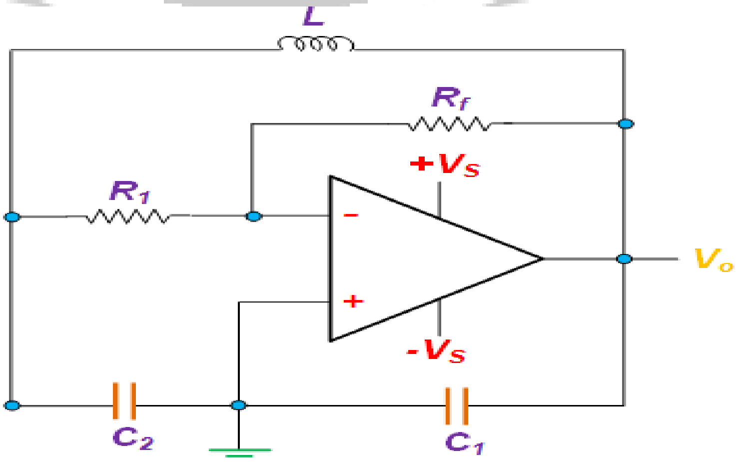


Figure 2 Colpitts Oscillator Using an Op-Amp

Apart from the BJT-based Colpitts Oscillator shown, they are also realizable using valves or FET (Field Effect Transistor) or Op-Amp. Figure 2 shows such a Colpitts oscillator which uses an Op-Amp in inverting configuration in its amplifier section while the tank circuit remains similar to that in the case of Figure 1. This kind of circuit functions almost analogous to that of the one explained earlier. However, here the gain of the oscillator can be adjusted individually just by using the feedback resistor R_f, as the gain of the inverting amplifier is given as $-R_f / R_1$. From this, it can be noted that, in this case, the gain of the circuit is less dependent on the circuit elements of the tank circuit.

Typically, the operating frequency of the Colpitts oscillators ranges from 20 KHz to 300 MHz. However they can even be used for microwave applications as their capacitors provide low reactance path for the high-frequency signals. This results in better frequency stability as well as a better sinusoidal output waveform. Moreover, they are also extensively used as surface acoustical wave (SAW) resonators, sensors and in mobile and communication systems.