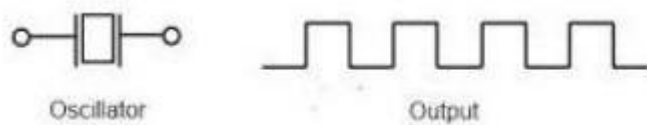


UNIT - II

OSCILLATORS

Introduction about Oscillators

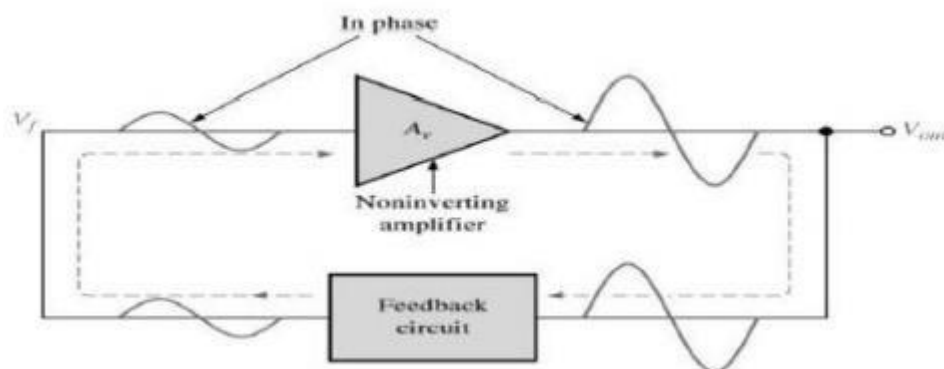
An oscillator is a circuit that produces a repetitive signal from a dc voltage. The feedback type oscillator which rely on a positive feedback of the output to maintain the oscillations. The relaxation oscillator makes use of an RC timing circuit to generate a non-sinusoidal signal such as square wave.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The requirements for oscillation are described by the Barkhausen criterion:

- The magnitude of the loop gain $A\beta$ must be 1.
- The phase shift of the loop gain $A\beta$ must be 0° or 360° or integer multiple of 2π



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

Amplitude stabilization:

- ✓ In both the oscillators above, the loop gain is set by component values
- ✓ In practice the gain of the active components is very variable
- ✓ If the gain of the circuit is too high it will saturate
- ✓ If the gain of the circuit is too low the oscillation will die.

Real circuits need some means of stabilizing the magnitude of the oscillation to cope with variability in the gain of the circuit

Barkhausen criterion

The conditions for oscillator to produce oscillation are given by Barkhausen criterion.

They are :

- The total phase shift produced by the circuit should be 360° or 0°
- The Magnitude of loop gain must be greater than or equal to 1 (ie) $|A\beta| \geq 1$

In practice loop gain is kept slightly greater than unity to ensure that oscillator work even if there is a slight change in the circuit parameters.

Mechanism of start of oscillation

The starting voltage is provided by noise, which is produced due to random motion of electrons in resistors used in the circuit. The noise voltage contains almost all the sinusoidal frequencies. This low amplitude noise voltage gets amplified and appears at the output terminals. The amplified noise drives the feedback network which is the phase shift network. Because of this the feedback voltage is maximum at a particular frequency, which in turn represents the frequency of oscillation.

LC Oscillator:

Oscillators are used in many electronic circuits and systems providing the central “clock” signal that controls that controls the sequential operation of the entire system. Oscillators convert a DC input (the supply voltage) into an AC output (the waveform), which can have a wide range of different wave shapes and frequencies that can be either complicated in nature or simple sine waves depending upon the application.

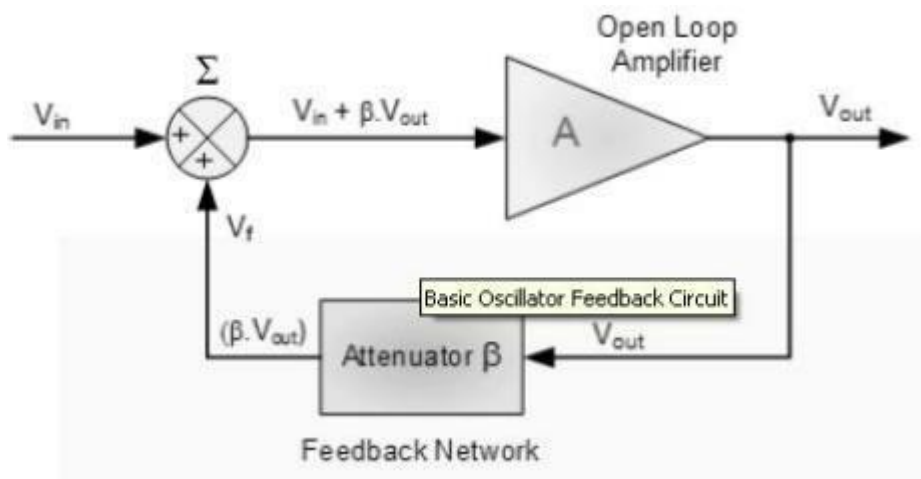
Oscillators are also used in many pieces of test equipment producing either sinusoidal sine wave, square, sawtooth or triangular shaped waveforms or just a train of pulse of a variable or constant width. LC Oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation.

An Oscillator is basically an Amplifier with “Positive Feedback”, or regenerative feedback (in-phase) and one of the many problems in electronic circuit design is stopping amplifiers from oscillating while trying to get oscillators to oscillate. Oscillators work because they overcome the losses of their feedback resonator circuit either in the form of a capacitor or both in the same circuit by applying DC energy at the required frequency into this resonator circuit.

In other words, an oscillator is a an amplifier which uses positive feedback that generates an output frequency without the use of an input signal.

It is self sustaining. Then an oscillator has a small signal feedback amplifier with an open-loop gain equal too or slightly greater than one for oscillations to start but to continue oscillations the average loop gain must return to unity. In addition to these reactive components, an amplifying device such as an Operational Amplifier or Bipolar Transistors required. Unlike an amplifier there is no external AC input required to cause the Oscillator to work as the DC supply energy is converted by the oscillator into AC energy at the required frequency.

Basic Oscillator Feedback Circuit



Where: β is a feedback fraction.

[Source: Jacob Millman, ‘Microelectronics’, McGraw Hill, 2nd Edition, Reprinted]

1. Without Feedback

$$\text{Gain, } A_v = \frac{V_{out}}{V_{in}}$$

A = open loop voltage gain

$$A_v \times V_{in} = V_{out}$$

2. With Feedback

$$A_v (V_{in} - \beta V_{out}) = V_{out} \quad \beta \text{ is the feedback fraction}$$

$$A_v V_{in} - A_v \beta V_{out} = V_{out} \quad A\beta = \text{the loop gain}$$

$$A_v V_{in} = V_{out}(1 + A\beta) \quad 1 + A\beta = \text{the feedback factor}$$

$$\therefore \frac{V_{out}}{V_{in}} = G_v = \frac{A}{1 + A\beta} \quad G_v = \text{the closed loop gain}$$

Oscillators are circuits that generate a continuous voltage output waveform at a required frequency with the values of the inductors, capacitors or resistors forming a frequency selective LC

resonant tank circuit and feedback network. This feedback network is an attenuation network which has a gain of less than one ($\beta < 1$) and starts oscillations when $A\beta > 1$ which returns to unity ($A\beta = 1$) once

oscillations commence. The LC oscillators frequency is controlled using a tuned or resonant inductive/capacitive (LC) circuit with the resulting output frequency being known as the Oscillation Frequency.

By making the oscillators feedback a reactive network the phase angle of the feedback will vary as a function of frequency and this is called Phase-shift.

There are basically types of Oscillators:\

1.Sinusoidal Oscillators - these are known as Harmonic Oscillators and are generally a “LC Tuned-feedback” or “RC tuned-feedback” type Oscillator that generates a purely sinusoidal waveform which is

of constant amplitude and frequency.

2.Non-Sinusoidal Oscillators – these are known as Relaxation Oscillators and generate complex non-sinusoidal waveforms that changes very quickly from one condition of stability to another such as

“Square-wave”, “Triangular-wave” or “Sawtoothed-wave” type waveforms.

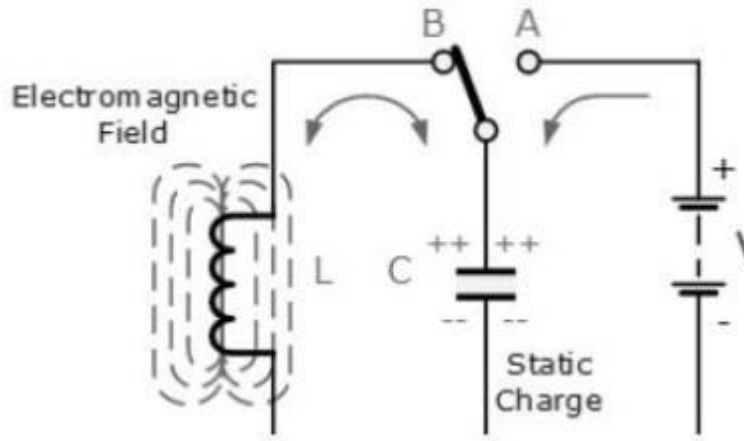
3. Resonance

When a constant voltage but of varying frequency is applied to a circuit consisting of an inductor, capacitor and resistor the reactance of both the Capacitor/Resistor and Inductor/Resistor circuits is to change both the amplitude and the phase of the output signal due to the reactance of the components used.

At high frequencies the reactance of a capacitor is very low acting as a short circuit while the reactance of the inductor is high acting as an open circuit. At low frequencies the reverse is true, the reactance of the capacitor acts as an open circuit and the reactance of the inductor acts as a short circuit.

Between these two extremes the combination of the inductor and capacitor produces a “Tuned” or “Resonant” circuit that has a Resonant Frequency, (f_r) in which the capacitive and inductive reactance’s are equal and cancel out each other, leaving only the resistance of the circuit to oppose the flow of current. This means that there is no phase shift as the current is in phase with the voltage. Consider the circuit below.

Basic LC Oscillator Tank Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The circuit consists of an inductive coil, L and a capacitor, C. The capacitor stores energy in the form of an electrostatic field and which produces a potential (static voltage) across its plates, while the inductive coil stores its energy in the form of an electromagnetic field.

The capacitor is charged up to the DC supply voltage, V by putting the switch in position A. When the capacitor is fully charged the switch changes to position B. The charged capacitor is now connected in parallel across the inductive coil so the capacitor begins to discharge itself through the coil.

The voltage across C starts falling as the current through the coil begins to rise. This rising current sets up an electromagnetic field around the coil which resists this flow of current. When the capacitor, C is completely discharged the energy that was originally stored in the capacitor, C as an electrostatic field is now stored in the inductive coil, L as an electromagnetic field around the coils windings.

As there is now no external voltage in the circuit to maintain the current within the coil, it starts to fall as the electromagnetic field begins to collapse. A back emf is induced in the coil ($e = -L \frac{di}{dt}$) keeping the current flowing in the original direction. This current now charges up the capacitor, c with the opposite polarity to its original charge.

C continues to charge up until the current reduces to zero and the electromagnetic field of the coil has collapsed completely. The energy originally introduced into the circuit through the switch, has been returned to the capacitor which again has an electrostatic voltage potential across it, although it is now of the opposite polarity. The capacitor now starts to discharge again back through the coil and

the whole process is repeated. The polarity of the voltage changes as the energy is passed back and forth between the capacitor and inductor producing an AC type sinusoidal voltage and current waveform.

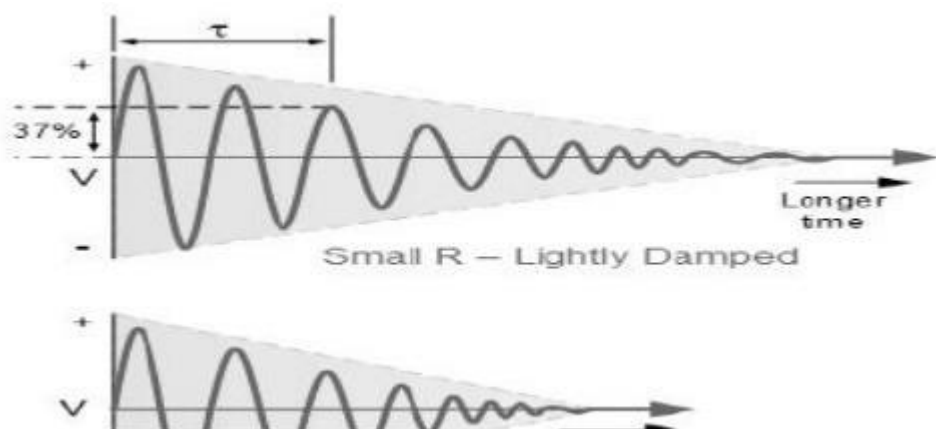
This then forms the basis of an LC oscillator's tank circuit and theoretically this cycling back and forth will continue indefinitely. However, every time energy is transferred from C to L or from L to C losses occur which decay the oscillations.

This oscillatory action of passing energy back and forth between the capacitor, C to the inductor, L would continue indefinitely if it was not for energy losses within the circuit. Electrical energy is lost in the DC or real resistance of the inductor's coil, in the dielectric of the capacitor, and in radiation from the circuit so the oscillation steadily decreases until they die away completely and the process stops.

Then in a practical LC circuit the amplitude of the oscillatory voltage decreases at each half cycle of oscillation and will eventually die away to zero. The oscillations are then said to be "damped" with the amount of damping being determined by the quality or Q-factor of the circuit.

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1. Damped Oscillations

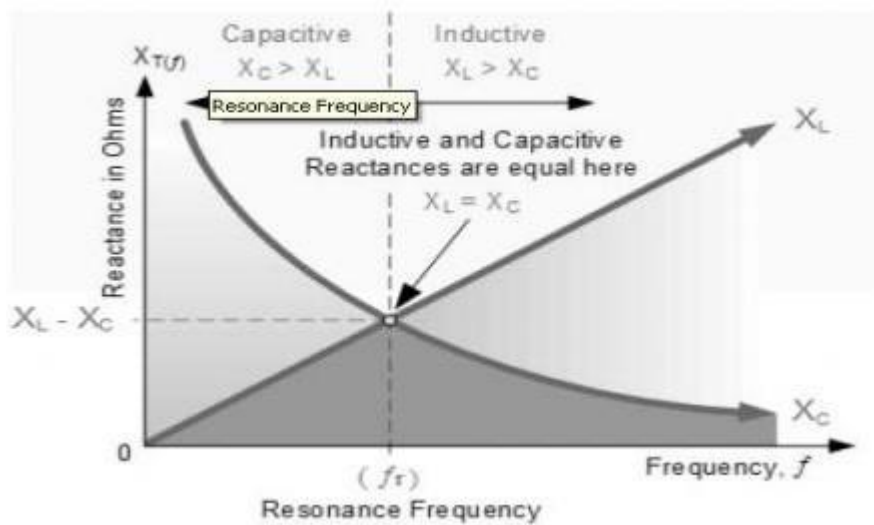


The frequency of the oscillatory voltage depends upon the value of the inductance and capacitance in the LC tank circuit. We now know that for resonance to occur in the tank circuit, there must be a frequency point where the value of X_C , the capacitive reactance is the same as the value of X_L , the inductive reactance ($X_L =$

X_C) and which will therefore cancel each other out leaving only the DC resistance in the circuit to oppose the flow of current.

If we now place the curve for inductive reactance on top of the curve for capacitive reactance so that both curves are on the same axes, the point of intersection will give us the resonance frequency point, (f_r or ω_r) as shown below.

2. Resonance Frequency



where: f_r is in Hertz, L is in Henries and C is in Farads.

Then the frequency at which this will happen is given as:

$$X_L = 2\pi fL \quad \text{and} \quad X_C = \frac{1}{2\pi fC}$$

$$\text{at resonance: } X_L = X_C$$

$$\therefore 2\pi fL = \frac{1}{2\pi fC}$$

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

$$\therefore f^2 = \frac{1}{(2\pi)^2 LC}$$

$$f = \frac{\sqrt{1}}{\sqrt{(2\pi)^2 LC}}$$

Then by simplifying the above equation we get the final equation for **Resonant**

Frequency, f_r in a tuned LC circuit as:

3. Resonant Frequency of a LC Oscillator

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

Where:

L is the Inductance in Henries

C is the Capacitance in Farads

f_r is the Output Frequency in Hertz

This equation shows that if either L or C are decreased, the frequency increases. This output frequency is commonly given the abbreviation of (f_r) to identify it as the "resonant frequency". To keep

the oscillations going in an LC tank circuit, we have to replace all the energy lost in each oscillation and also maintain the amplitude of these oscillations at a constant level.

The amount of energy replaced must therefore be equal to the energy lost during each cycle. If the energy replaced is too large the amplitude would increase until clipping of the supply rails occurs. Alternatively, if the amount of energy replaced is too small the amplitude would eventually decrease to zero over time and the oscillations would stop.

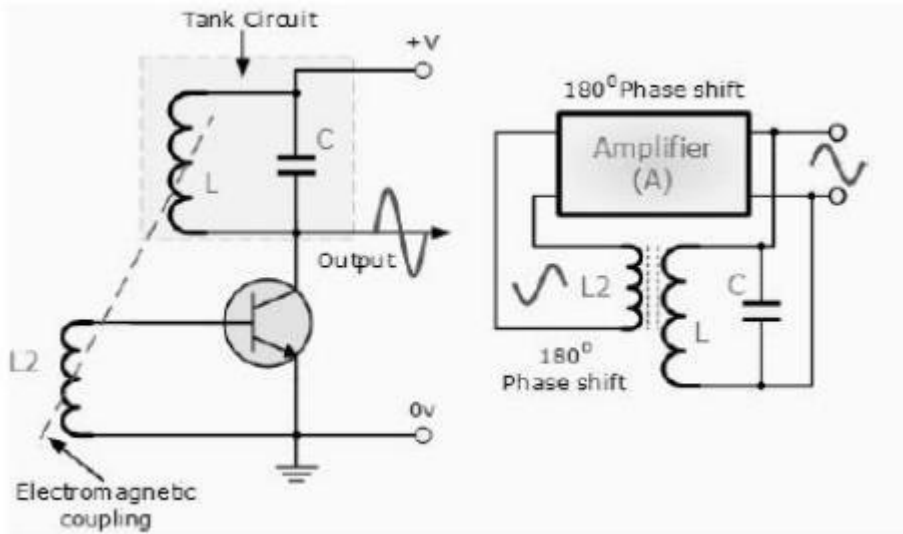
The simplest way of replacing this lost energy is to take part of the output from the LC tank circuit, amplify it and then feed it back into the LC circuit again. This process can be achieved using a voltage amplifier using an op-amp, FET or bipolar transistor as its active device.

However, if the loop gain of the feedback amplifier is too small, the desired oscillation decays to zero and if it is too large, the waveform becomes distorted. To produce a constant oscillation, the level of the energy fed back to the LC network must be accurately controlled.

Then there must be some form of automatic amplitude or gain control when the amplitude tries to vary from a reference voltage either up or down. To maintain a stable oscillation the overall gain of the circuit must be equal to one or unity. Any less and the oscillations will not start or die away to zero, any more the oscillations will occur but the amplitude will become clipped by the supply rails causing distortion. Consider the circuit below.

Basic Transistor LC Oscillator Circuit

[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]



A Bipolar Transistor is used as the LC oscillators amplifier with the tuned LC tank circuit acts as the collector load. Another coil L2 is connected between the base and the emitter of the transistor whose electromagnetic field is "mutually" coupled with that of coil L. Mutual inductance exists between the two circuits.

The changing current flowing in one coil circuit induces, by electromagnetic induction, a potential voltage in the other (transformer effect) so as the oscillations occur in the tuned circuit, electromagnetic energy is transferred from coil L to coil L2 and a voltage of the same frequency as that in the tuned circuit is applied between the base and emitter of the transistor.

In this way the necessary automatic feedback voltage is applied to the amplifying transistor. The amount of feedback can be increased or decreased by altering the coupling between the two coils L and L2. When the circuit is oscillating its impedance is resistive and the collector and base voltages are 180 out of phase. In order to maintain oscillations (called frequency stability) the voltage applied to the tuned circuit must be "in-phase" with the oscillations occurring in the tuned circuit.

Therefore, we must introduce an additional 180° phase shift into the feedback path between the collector and the base. This is achieved by winding the coil of L2 in the correct direction relative to coil L giving us the correct amplitude and phase relationships for the Oscillators circuit or by connecting a phase shift network between the output and input of the amplifier.

The LC Oscillator is therefore a "Sinusoidal Oscillator" or a "Harmonic Oscillator" as it is more commonly called. LC oscillators can generate high

frequency sine waves for use in radio frequency (RF) type applications with the transistor amplifier being of a Bipolar Transistor or FET.

Harmonic Oscillators come in many different forms because there are many different ways to construct an LC filter network and amplifier with the most common being the Hartley LC Oscillator, Colpitts LC Oscillator, Armstrong Oscillator and Clapp Oscillator to name a few.

The Hartley Oscillator

The main disadvantages of the basic LC Oscillator circuit we looked at in the previous tutorial is that they have no means of controlling the amplitude of the oscillations and also, it is difficult to tune the oscillator to the required frequency.

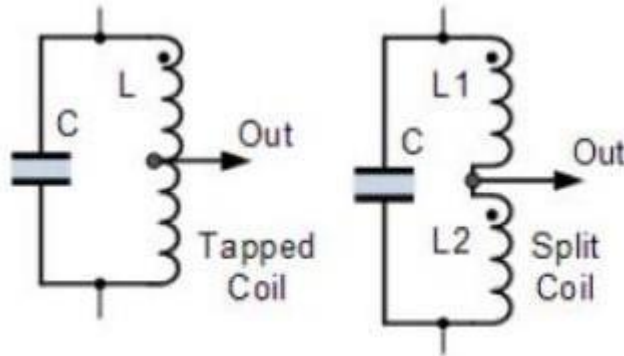
If the cumulative electromagnetic coupling between L1 and L2 is too small there would be insufficient feedback and the oscillations would eventually die away to zero Likewise if the feedback was too strong the oscillations would continue to increase in amplitude until they were limited by the circuit conditions producing signal distortion. So it becomes very difficult to "tune" the oscillator.

However, it is possible to feed back exactly the right amount of voltage for constant amplitude oscillations. If we feed back more than is necessary the amplitude of the oscillations can be controlled by biasing the amplifier in such a way that if the oscillations increase in amplitude, the bias is increased and the gain of the amplifier is reduced.

If the amplitude of the oscillations decreases the bias decreases and the gain of the amplifier increases, thus increasing the feedback. In this way the amplitude of the oscillations are kept constant using a process known as Automatic Base Bias.

One big advantage of automatic base bias in a voltage controlled oscillator, is that the oscillator can be made more efficient by providing a Class-B bias or even a Class-C bias condition of the transistor. This has the advantage that the collector current only flows during part of the oscillation cycle so the quiescent collector current is very small.

Then this "self-tuning" base oscillator circuit forms one of the most common types of LC parallel resonant feedback oscillator configurations called the Hartley Oscillator circuit.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

1. Hartley Oscillator Tuned Circuit

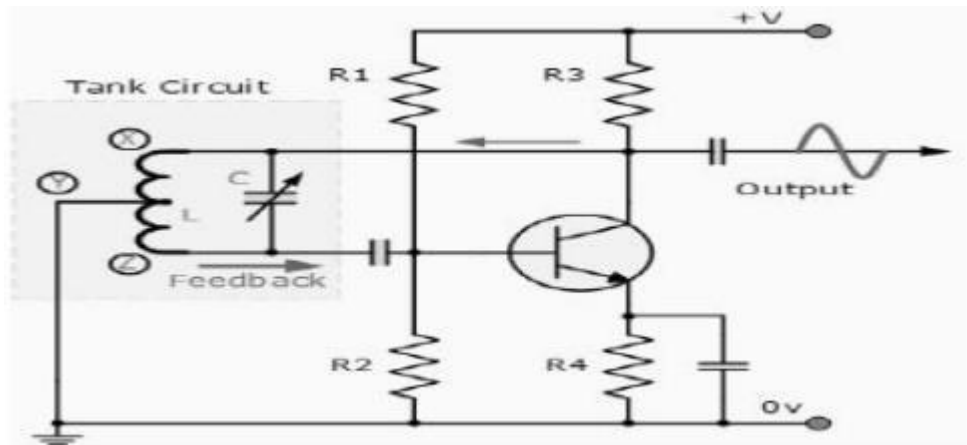
In the Hartley Oscillator the tuned LC circuit is connected between the collector and the base of the transistor amplifier. As far as the oscillatory voltage is concerned, the emitter is connected to a tapping point on the tuned circuit coil.

The feedback of the tuned tank circuit is taken from the centre tap of the inductor coil or even two separate coils in series which are in parallel with a variable capacitor, C as shown.

The Hartley circuit is often referred to as a split-inductance oscillator because coil L is centre-tapped. In effect, inductance L acts like two separate coils in very close proximity with the current flowing through coil section XY induces a signal into coil section YZ below.

An Hartley Oscillator circuit can be made from any configuration that uses either a single tapped coil (similar to an autotransformer) or a pair of series connected coils in parallel with a single capacitor as shown below.

2. Basic Hartley Oscillator Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

When the circuit is oscillating, the voltage at point X (collector), relative to point Y (emitter), is 180° out-of-phase with the voltage at point Z (base) relative to point Y. At the frequency of oscillation, the impedance of the Collector load is resistive and an increase in Base voltage causes a decrease in the Collector voltage. Then there is a 180 phase change in the voltage between the Base and Collector and this along with the original 180 phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained.

The amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa.

Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors.

In this Hartley Oscillator circuit, the DC Collector current flows through part of the coil and for this reason the circuit is said to be "Series-fed" with the frequency of oscillation of the Hartley Oscillator being given as.

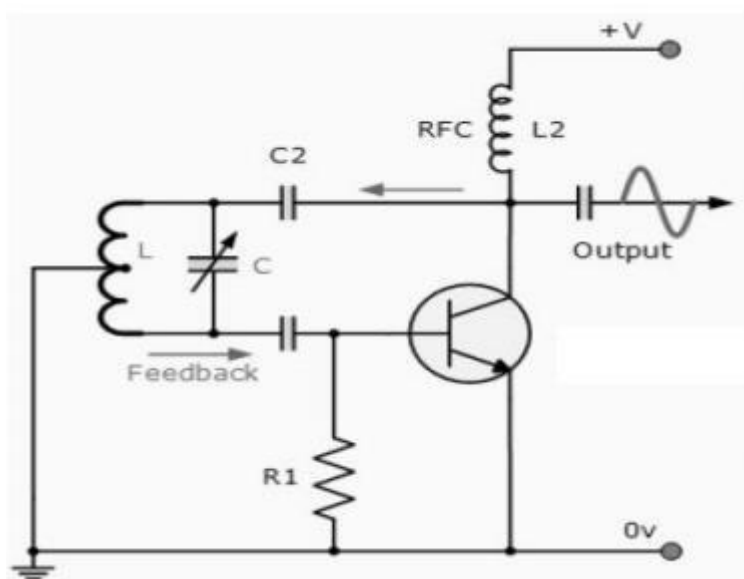
$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

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

The frequency of oscillations can be adjusted by varying the "tuning" capacitor, C or by varying the position of the iron-dust core inside the coil (inductive tuning) giving an output over a wide range of frequencies making it very easy to tune. Also the Hartley Oscillator produces an output amplitude which is constant over the entire frequency range.

As well as the Series-fed Hartley Oscillator above, it is also possible to connect the tuned tank circuit across the amplifier as a shunt-fed oscillator as shown below.

3. Shunt-fed Hartley Oscillator Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

In the Shunt-fed Hartley Oscillator both the AC and DC components of the Collector current have separate paths around the circuit. Since the DC component is blocked by the capacitor, C2 no DC flows through the inductive coil, L and less power is wasted in the tuned circuit.

The Radio Frequency Coil (RFC), L2 is an RF choke which has a high reactance at the frequency of oscillations so that most of the RF current is applied to the LC tuning tank circuit via capacitor, C2 as the DC component passes through L2 to the power supply. A resistor could be used in place of the RFC coil, L2 but the efficiency would be less.

Armstrong oscillator

The **Armstrong oscillator** (also known as **Meissner oscillator**) is named after the electrical engineer Edwin Armstrong, its inventor. It is sometimes called a tickler

oscillator because the feedback needed to produce oscillations is provided using a tickler coil via magnetic coupling between coil L and coil T.

Assuming the coupling is weak, but sufficient to sustain oscillation, the frequency is determined primarily by the tank circuit (**L** and **C** in the illustration) and is approximately given by. In a practical circuit, the actual oscillation frequency will be slightly different from the value provided by this formula because of stray capacitance and inductance, internal losses (resistance), and the loading of the tank circuit by the tickler coil.

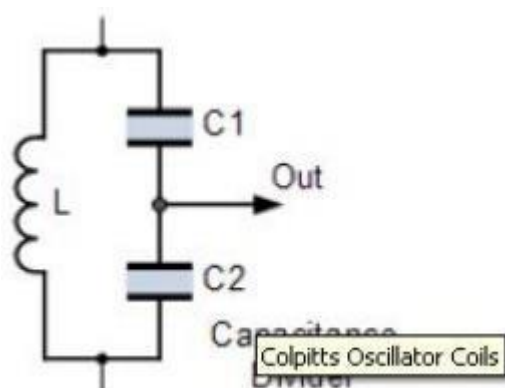
This circuit is the basis of the regenerative receiver for amplitude modulated radio signals. In that application, an antenna is attached to an additional tickler coil, and the feedback is reduced, for example, by slightly increasing the distance between coils **T** and **L**, so the circuit is just short of oscillation.

The result is a narrow-band radio-frequency filter and amplifier. The non-linear characteristic of the transistor or tube provides the demodulated audio signal.

The Colpitts Oscillator

The Colpitts Oscillator, named after its inventor Edwin Colpitts is another type of LC oscillator design. In many ways, the Colpitts oscillator is the exact opposite of the Hartley Oscillator we looked at in the previous tutorial. Just like the Hartley oscillator, the tuned tank circuit consists of an LC resonance sub-circuit connected between the collector and the base of a single stage transistor amplifier producing a sinusoidal output waveform.

The basic configuration of the Colpitts Oscillator resembles that of the Hartley Oscillator but the difference this time is that the centre tapping of the tank sub-circuit is now made at the junction of a "capacitive voltage divider" network instead of a tapped autotransformer type inductor as in the Hartley oscillator.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

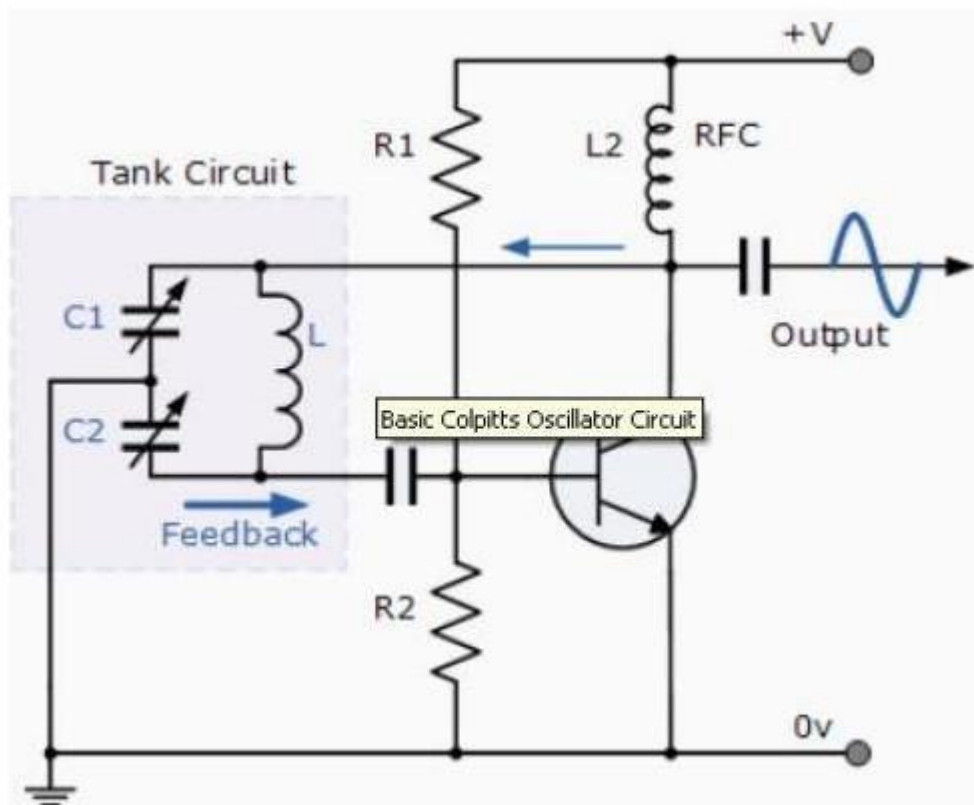
Colpitts Oscillator Circuit

The Colpitts oscillator uses a capacitor voltage divider as its feedback source.

The two capacitors, C1 and C2 are placed across a common inductor, L as shown so that C1, C2 and L forms the tuned tank circuit the same as for the Hartley oscillator circuit.

The advantage of this type of tank circuit configuration is that with less self and mutual inductance in the tank circuit, frequency stability is improved along with a more simple design. As with the Hartley oscillator, the Colpitts oscillator uses a single stage bipolar transistor amplifier as the gain element which produces a sinusoidal output. Consider the circuit below.

1. Basic Colpitts Oscillator Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The transistor amplifier's emitter is connected to the junction of capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is first applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to

the base-emitter junction and appear in the amplified at the collector output. The amount of feedback depends on the values of C1 and C2 with the smaller the values of C the greater will be the feedback.

The required external phase shift is obtained in a similar manner to that in the Hartley oscillator circuit with the required positive feedback obtained for sustained un-damped oscillations. The amount of feedback is determined by the ratio of C1 and C2 which are generally "ganged" together to provide a constant amount of feedback so as one is adjusted the other automatically follows.

The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

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

where C_T is the capacitance of C1 and C2 connected in series and is given as:.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

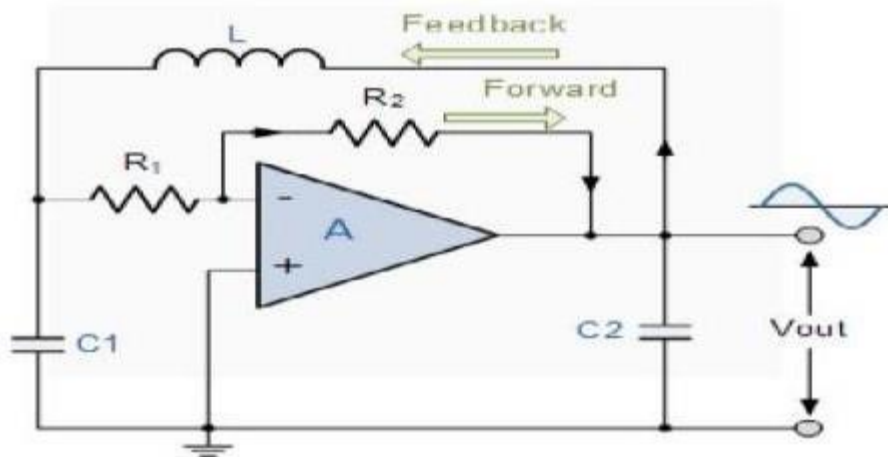
The configuration of the transistor amplifier is of a Common Emitter Amplifier with the output signal 180° out of phase with regards to the input signal. The additional 180° phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360°. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitor acts as a DC-blocking capacitors. The radio-frequency choke (RFC) is used to provide a high reactance (ideally open circuit) at the frequency of oscillation, (f_r) and a low resistance at DC.

2. Colpitts Oscillator using an Op-amp

As well as using a bipolar junction transistor (BJT) as the amplifiers active stage of the Colpitts oscillator, we can also use either a field effect transistor, (FET) or an operational amplifier, (op-amp). The operation of an **Op-amp Colpitts**

Oscillator is exactly the same as for the transistorised version with the frequency of operation calculated in the same manner. Consider the circuit below.

3. Colpitts Oscillator Op-amp Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

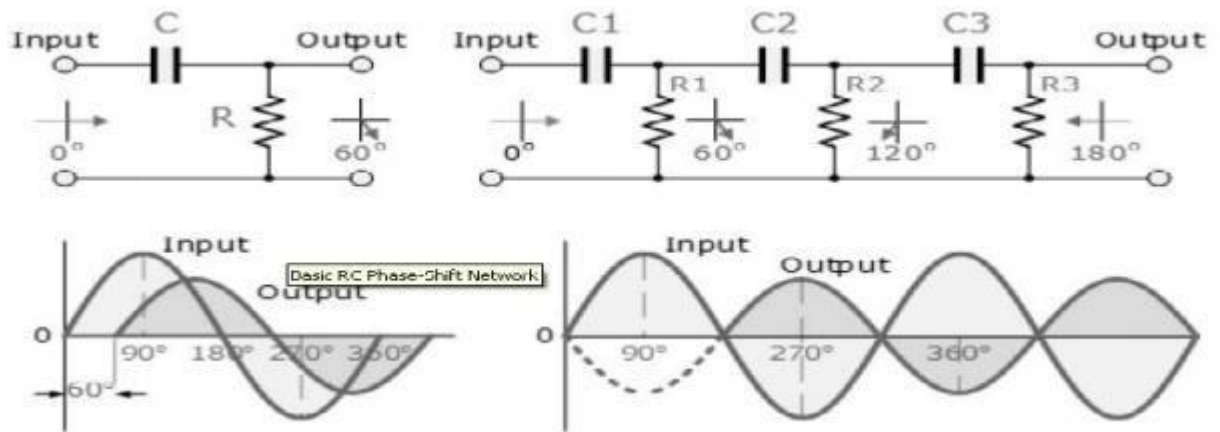
The advantages of the Colpitts Oscillator over the Hartley oscillators are that the Colpitts oscillator produces a more purer sinusoidal waveform due to the low impedance paths of the capacitors at high frequencies. Also due to these capacitive reactance properties the Colpitts oscillator can operate at very high frequencies into the microwave region.

RC Phase-Shift Oscillator

In a RC Oscillator the input is shifted 180° through the amplifier stage and 180° again through a second inverting stage giving us " $180^\circ + 180^\circ = 360^\circ$ " of phase shift which is the same as 0° thereby giving us the required positive feedback. In other words, the phase shift of the feedback loop should be " 0° ".

In a Resistance-Capacitance Oscillator or simply an RC Oscillator, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same network by using RC elements in the feedback branch, for example.

RC Phase-Shift Network

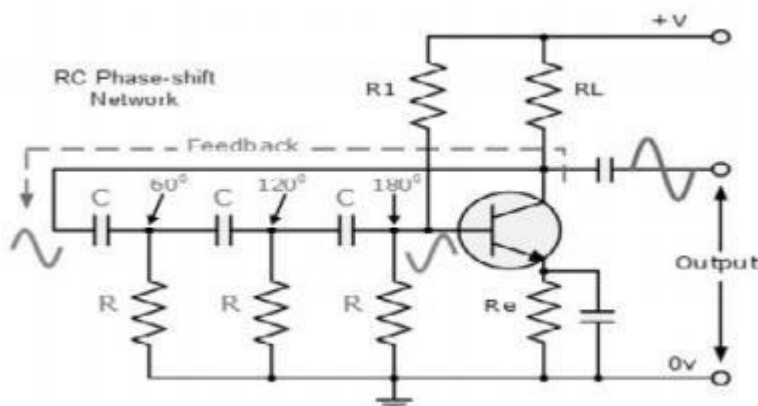


[Source: Jacob Millman, ‘Microelectronics’, McGraw Hill, 2nd Edition, Reprinted]

The circuit on the left shows a single resistor-capacitor network and whose output voltage "leads" the input voltage by some angle less than 90°. An ideal RC circuit would produce a phase shift of exactly 90°. The amount of actual phase shift in the circuit depends upon the values of the resistor and the capacitor, and the chosen frequency of oscillations with the phase angle (Φ) being given as:

$$\phi = \tan^{-1} \frac{X_C}{R}$$

RC Oscillator Circuit



[Source: Jacob Millman, ‘Microelectronics’, McGraw Hill, 2nd Edition, Reprinted]

The RC Oscillator which is also called a Phase Shift Oscillator, produces a sine wave output signal using regenerative feedback from the resistor-capacitor

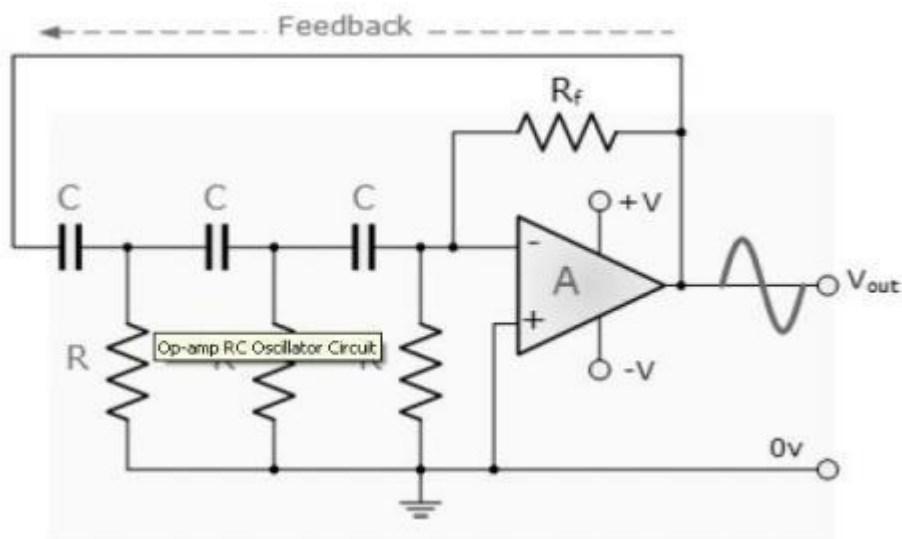
combination. This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).

This resistor-capacitor feedback network can be connected as shown above to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360°. By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done using a 3-ganged variable capacitor

If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as:

$$f = \frac{1}{2\pi CR\sqrt{6}}$$

Op-amp RC Oscillator Circuit



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

As the feedback is connected to the non-inverting input, the operational amplifier is therefore connected in its "inverting amplifier" configuration which produces the required 180° phase shift while the RC network produces the other 180° phase shift at the required frequency (180° + 180°).

Although it is possible to cascade together only two RC stages to provide the required 180° of phase shift ($90^\circ + 90^\circ$), the stability of the oscillator at low frequencies is poor.

One of the most important features of an RC Oscillator is its frequency stability which is its ability too provide a constant frequency output under varying load conditions. By cascading three or even four RC stages together ($4 \times 45^\circ$), the stability of the oscillator can be greatly improved.

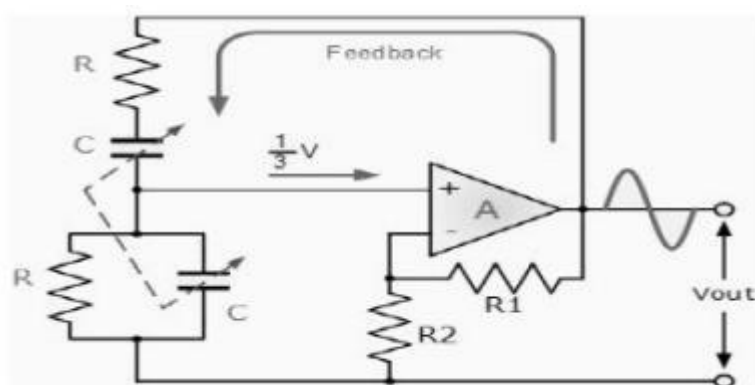
RC Oscillators with four stages are generally used because commonly available operational amplifiers come in quad IC packages so designing a 4- stage oscillator with 45° of phase shift relative to each other is relatively easy.

WIEN BRIDGE OSCILLATOR

One of the simplest sine wave oscillators which uses a RC network in place of the conventional LC tuned tank circuit to produce a sinusoidal output waveform, is the Wien Bridge Oscillator.

The Wien Bridge Oscillator is so called because the circuit is based on a frequency-selective form of the Whetstone bridge circuit. The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune making it a popular circuit as an audio frequency oscillator

Wien Bridge Oscillator



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The output of the operational amplifier is fed back to both the inputs of the amplifier. One part of the feedback signal is connected to the inverting input terminal (negative feedback) via the resistor divider network of R1 and R2 which allows the amplifiers voltage gain to be adjusted within narrow limits.

The other part is fed back to the non-inverting input terminal (positive feedback) via the RC Wien Bridge network. The RC network is connected in the positive feedback path of the amplifier and has zero phase shift at just one frequency. Then at the selected resonant frequency, (f_r) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" so the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.

Also the voltage gain of the amplifier circuit MUST be equal to three "Gain =3" for oscillations to start. This value is set by the feedback resistor network, R1 and R2 for an inverting amplifier and is given as the ratio $-R1/R2$.

Also, due to the open-loop gain limitations of operational amplifiers, frequencies above 1MHz are unachievable without the use of special high frequency op-amps. Then for oscillations to occur in a Wien Bridge Oscillator circuit the following conditions must apply.

- With no input signal the Wien Bridge Oscillator produces output oscillations.
- The Wien Bridge Oscillator can produce a large range of frequencies.
- The Voltage gain of the amplifier must be at least 3.
- The network can be used with a Non-inverting amplifier.
- The input resistance of the amplifier must be high compared to R so that the RC network is not overloaded and alter the required conditions.
- The output resistance of the amplifier must be low so that the effect of external loading is minimised.
- Some method of stabilizing the amplitude of the oscillations must be provided because if the voltage gain of the amplifier is too small the desired oscillation will decay and stop and if it is too large the output amplitude rises to the value of the supply rails, which saturates the op-amp and causes the output waveform to become distorted.
- With amplitude stabilisation in the form of feedback diodes, oscillations from the oscillator can go on indefinitely.

Quartz Crystal Oscillators

One of the most important features of any oscillator is its frequency stability, or in other words its ability to provide a constant frequency output under varying load conditions. Some of the factors that affect the frequency stability of an oscillator include: temperature, variations in the load and changes in the DC power supply.

Frequency stability of the output signal can be improved by the proper selection of the components used for the resonant feedback circuit including the amplifier but there is a limit to the stability that can be obtained from normal LC and RC tank circuits.

To obtain a very high level of oscillator stability a Quartz Crystal is generally used as the frequency determining device to produce another types of oscillator circuit known generally as a Quartz Crystal Oscillator, (XO).

[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]



Crystal Oscillator

When a voltage source is applied to a small thin piece of quartz crystal, it begins to change shape producing a characteristic known as the Piezo-electric effect.

This piezo-electric effect is the property of a crystal by which an electrical charge produces a mechanical force by changing the shape of the crystal and vice versa, a mechanical force applied to the crystal produces an electrical charge.

Then, piezo-electric devices can be classed as Transducers as they convert energy of one kind into energy of another (electrical to mechanical or mechanical to electrical).

This piezo-electric effect produces mechanical vibrations or oscillations which are used to replace the LC tank circuit in the previous oscillators.

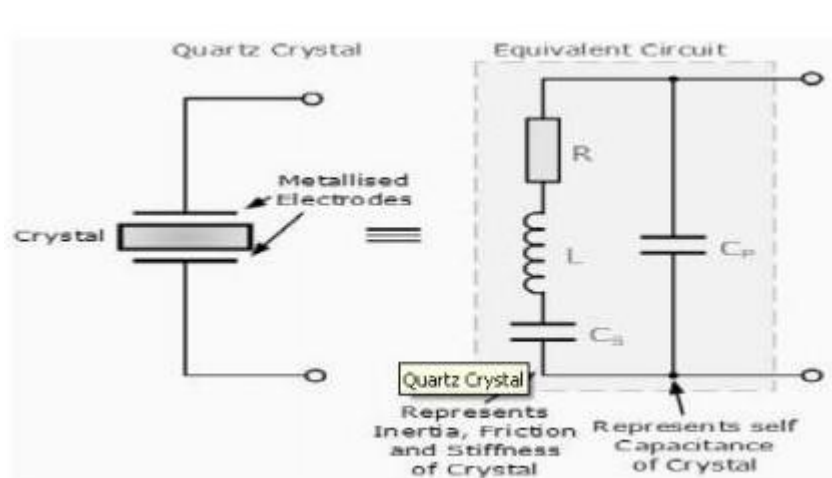
There are many different types of crystal substances which can be used as oscillators with the most important of these for electronic circuits being the quartz minerals because of their greater mechanical strength.

The quartz crystal used in a Quartz Crystal Oscillator is a very small, thin piece or wafer of cut quartz with the two parallel surfaces metallised to make the

required electrical connections. The physical size and thickness of a piece of quartz crystal is tightly controlled since it affects the final frequency of oscillations and is called the crystals "characteristic frequency". Then once cut and shaped, the crystal can not be used at any other frequency. In other words, its size and shape determines its frequency.

The crystals characteristic or resonant frequency is inversely proportional to its physical thickness between the two metallised surfaces. A mechanically vibrating crystal can be represented by an equivalent electrical circuit consisting of low resistance, large inductance and small capacitance as shown below.

Quartz Crystal

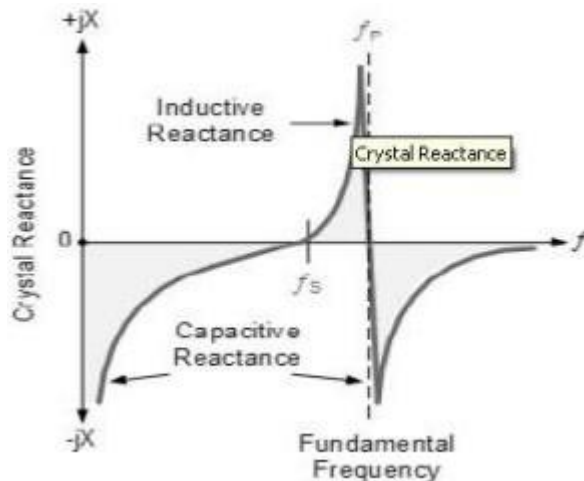


[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The equivalent circuit for the quartz crystal shows an RLC series circuit, which represents the mechanical vibrations of the crystal, in parallel with a capacitance, C_p which represents the electrical connections to the crystal. Quartz crystal oscillators operate at "parallel resonance", and the equivalent impedance of the crystal has a series resonance where C_s resonates with inductance, L and a parallel resonance where L resonates with the series combination of C_s and C_p as shown.

Crystal Reactance

The slope of the reactance against frequency above, shows that the series reactance at frequency f_s is inversely proportional to C_s because below f_s and above f_p the crystal appears capacitive, i.e. dX/df , where X is the reactance.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

The slope of the reactance against frequency above, shows that the series reactance at frequency f_s is inversely proportional to C_s because below f_s and above f_p the crystal appears capacitive, i.e. dX/df , where X is the reactance. Between frequencies f_s and f_p , the crystal appears inductive as the two parallel capacitances cancel out. The point where the reactance values of the capacitances and inductance cancel each other out $X_c = X_L$ is the fundamental frequency of the crystal.

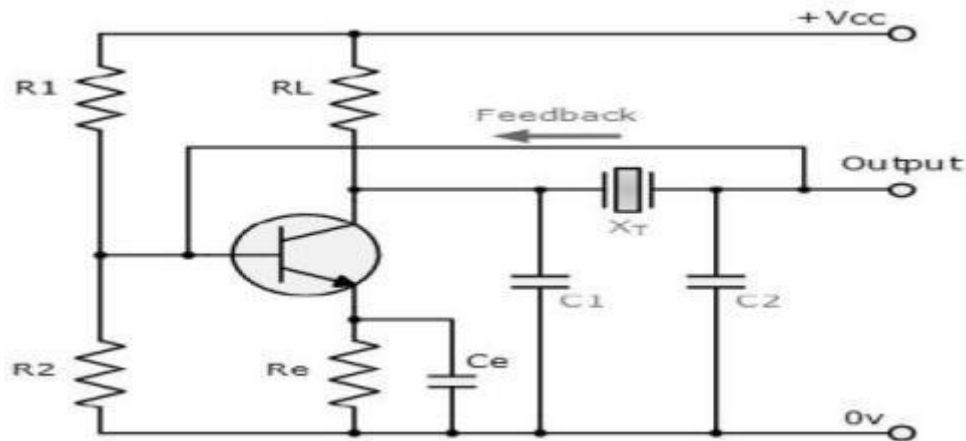
A quartz crystal has a resonant frequency similar to that of an electrically tuned tank circuit but with a much higher Q factor due to its low resistance, with typical frequencies ranging from 4kHz to 10MHz. The cut of the crystal also determines how it will behave as some crystals will vibrate at more than one frequency. Also, if the crystal is not of a parallel or uniform thickness it has two or more resonant frequencies having both a fundamental frequency and harmonics such as second or third harmonics. However, usually the fundamental frequency is more stronger or pronounced than the others and this is the one used. The equivalent circuit above has three reactive components and there are two resonant frequencies, the lowest is a series type frequency and the highest a parallel type resonant frequency.

We have seen in the previous tutorials, that an amplifier circuit will oscillate if it has a loop gain greater or equal to one and the feedback is positive. In a Quartz Crystal Oscillator circuit the oscillator will oscillate at the crystal's fundamental parallel resonant frequency as the crystal always wants to oscillate when a voltage source is applied to it.

However, it is also possible to "tune" a crystal oscillator to any even harmonic of the fundamental frequency, (2nd, 4th, 8th etc.) and these are known generally as Harmonic Oscillators while Overtone Oscillators vibrate at odd multiples of the fundamental frequency, (3rd, 5th, 11th etc). Generally, crystal oscillators that operate at overtone frequencies do so using their series resonant frequency.

Colpitts Crystal Oscillator:

The design of a Crystal Oscillator is very similar to the design of the Colpitts Oscillator we looked at in the previous tutorial, except that the LC tank circuit has been replaced by a quartz crystal as shown below.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

These types of Crystal Oscillators are designed around the common emitter amplifier stage of a Colpitts Oscillator. The input signal to the base of the transistor is inverted at the transistor's output. The output signal at the collector is then taken through a 180° phase shifting network which includes the crystal operating in a series resonant mode. The output is also fed back to the input which is "in-phase" with the input providing the necessary positive feedback. Resistors, R1 and R2 bias the resistor in a Class A type operation while resistor

Re is chosen so that the loop gain is slightly greater than unity.

Capacitors, C1 and C2 are made as large as possible in order that the frequency of oscillations can approximate to the series resonant mode of the crystal and is not dependant upon the values of these capacitors.

The circuit diagram above of the Colpitts Crystal Oscillator circuit shows that capacitors, C1 and C2 shunt the output of the transistor which reduces the feedback signal.

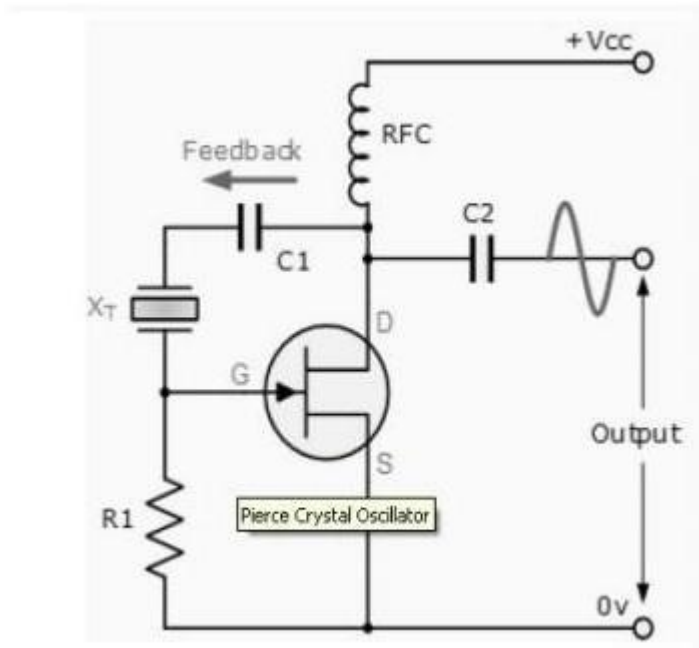
Therefore, the gain of the transistor limits the maximum values of C1 and C2.

The output amplitude should be kept low in order to avoid excessive power dissipation in the crystal otherwise could destroy itself by excessive vibration.

Pierce Oscillator

The Pierce oscillator is a crystal oscillator that uses the crystal as part of its feedback path and therefore has no resonant tank circuit. The Pierce Oscillator uses a JFET as its amplifying device as it provides a very high input impedance with the crystal connected between the output Drain terminal and the input Gate terminal as shown below.

Pierce Crystal Oscillator



[Source: Jacob Millman, ‘Microelectronics’, McGraw Hill, 2nd Edition, Reprinted]

In this simple circuit, the crystal determines the frequency of oscillations and operates on its series resonant frequency giving a low impedance path between output and input.

There is a 180° phase shift at resonance, making the feedback positive. The amplitude of the output sine wave is limited to the maximum voltage range at the Drain terminal.

Resistor, R1 controls the amount of feedback and crystal drive while the voltage across the radio frequency choke, RFC reverses during each cycle. Most digital clocks, watches and timers use a Pierce Oscillator in some form or other as it can be implemented using the minimum of components.

Important Short Questions and Answers: Oscillators

Electronic Circuits - Oscillators - Important Short Questions and Answers: Oscillators

OSCILLATORS

1. Mention two essential conditions for a circuit to maintain oscillations[

The conditions for oscillator to produce oscillation are given by Barkhausen criterion. They are:

- i) The total phase shift produced by the circuit should be 360° or 0°
- ii) The Magnitude of loop gain must be greater than or equal to 1 (ie) $|A\beta| \geq 1$

2. What is the major disadvantage of a Twin-T oscillator?

Twin –T oscillator is operated only at one frequency.

3. Differentiate oscillator from amplifier.

Oscillators

1. They are self-generating circuits. They generate waveforms like sine, square and triangular waveforms of their own. Without having input signal.
2. It have infinite gain
3. Oscillator uses positive feedback.

Amplifiers

1. They are not self-generating circuits. They need a signal at the input and they just increase the level of the input waveform.
2. It have finite gain
3. Amplifier uses negative feedback.

4. State Barkhausen criterion for sustained oscillation. What will happen to the oscillation if the magnitude of the loop gain is greater than unity?

The conditions for oscillator to produce oscillation are given by Barkhausen criterion. They are :

- i) The total phase shift produced by the circuit should be 360° or 0°
- ii) The Magnitude of loop gain must be greater than or equal to 1 (ie) $|A\beta| \geq 1$

In practice loop gain is kept slightly greater than unity to ensure that oscillator work even if there is a slight change in the circuit parameters.

5. Why an LC tank circuit does not produce sustained oscillations. How can this can be overcome?

We know that the inductor coil has some resistance and dielectric material of the capacitor has some leakage. so small part of the originally imparted energy is used to overcome these losses. As a result, the amplitude of oscillating current goes on decreasing and becomes zero when all energy is consumed as losses. So a LC tank circuit does not produce sustained oscillations.

To maintain sustained oscillations, energy must be supplied to the circuit at the same rate at which it is dissipated. In an oscillator, the function of transistor and power supply source is to feed energy to the circuit to overcome the losses at right time.

6. Draw the electrical equivalent circuit of crystal. and mention its series and parallel resonance frequency.

The crystal actually behaves as a series RLC circuit in parallel with C_M . Because of presence of C_M , the crystal has two resonant frequencies.

One of these is the series resonant frequency f_s . In this case impedance is very low.

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

• The other is parallel resonance frequency f_p . In this case impedance is very high.

$$f_p = \frac{1}{2\pi\sqrt{LC_{sq}}}, \text{ where } C_{sq} = \frac{CC_M}{C + C_M}$$

7. What are the advantages and disadvantages of RC phase shift oscillators?.

Advantages:

- i. It is best suited for generating fixed frequency signals in the audio frequency range.
 - ii. It requires no transformer or inductor, hence less bulky.
 - iii. Simple Circuit.
- *Pure sine wave output is possible.

Disadvantages:

- i) It requires a high β transistor to overcome losses in the network.
- ii) These oscillators are not suitable for high frequency operation.
- iii) Frequency of oscillation can not be changed easily. To change the frequency of oscillation, the three capacitor or resistors should be changed simultaneously. This is inconvenient.

8. What is the necessary condition for a Wien bridge oscillator circuit to have sustained oscillations?

Then for oscillations to occur in a **Wien Bridge Oscillator** circuit the following conditions must apply.

- ✓ With no input signal the Wien Bridge Oscillator produces output oscillations.
- ✓ The Wien Bridge Oscillator can produce a large range of frequencies.
- ✓ The Voltage gain of the amplifier must be at least 3.
- ✓ The network can be used with a Non-inverting amplifier.
- ✓ The input resistance of the amplifier must be high compared to R so that the RC network is not overloaded and alter the required conditions.
- ✓ The output resistance of the amplifier must be low so that the effect of external loading is minimised.

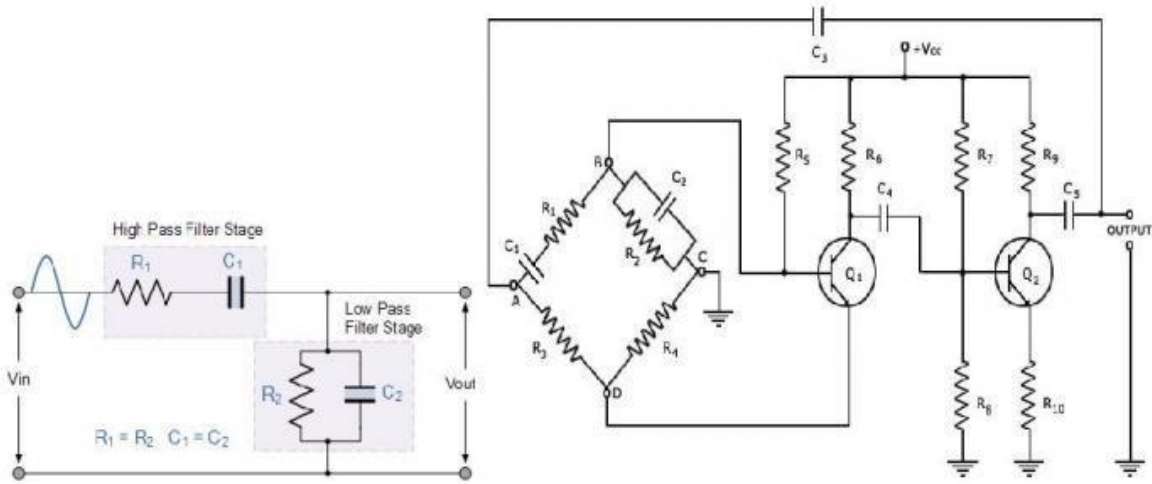
9. Define piezoelectric effect.

The piezo electric Crystals exhibit a property that if a mechanical stress is applied across one face the electric potential is developed across opposite face and viceversa. This phenomenon is called piezo electric effect.

10. What is the principle behind operation of a crystal oscillator?

The principle behind the operation of crystal is piezoelectric effect. According to this effect, if a mechanical stress is applied across one face the electric potential is developed across opposite face and viceversa.

11. Draw an oscillator circuit with feedback network given below.



[Source: Jacob Millman, 'Microelectronics', McGraw Hill, 2nd Edition, Reprinted]

12. What are the advantages and disadvantages of wein bridge oscillators? Advantages:

1. Provides a stable low distortion sinusoidal output over a wide range of frequency.
2. The frequency range can be selected simply by using decade resistance boxes.
3. The frequency of oscillation can be easily varied by varying capacitances C_1 and C_2 simultaneously. The overall gain is high because of two transistors.

Disadvantages :

1. The circuit needs two transistors and a large number of other components.
2. The maximum frequency output is limited because of amplitude and the phase-shift characteristics of amplifier.

13. A weinbridge oscillator is used for operations at 9KHz. If the value of resistance R is 100KΩ, what is the value of C required?

14. A weinbridge oscillator is used for operations at 10KHz. If the value of resistance R is 100KΩ, what is the value of C required?

15. A tuned collector oscillator in a radio receiver has a fixed inductance of $60\mu\text{H}$ and has to be tunable over the frequency band of 400KHz to 1200KHz . Find the range of variable capacitor to be used.

16. Draw the feedback circuit of a colpitts oscillator. Obtain the value of the equivalent series capacitance required if it uses a L of 100mH and is to oscillate at 40KHz .

17. In a Hartley oscillator if $L_1=0.2\text{mH}$, $L_2=0.3\text{mH}$ and $C=0.003\mu\text{F}$. calculate the frequency of its oscillations.

18. In an RC phase shift oscillator, if its frequency of oscillation is 955Hz and $R_1=R_2=R_3=680\text{K}\Omega$. Find the value of capacitors.

19. In an RC phase shift oscillator, if $R_1=R_2=R_3=200\text{K}\Omega$ and $C_1=C_2=C_3=100\text{pF}$. Find the frequency of the oscillator.

20. A crystal has the following parameters $L=0.5\text{H}$, $C=0.05\text{pF}$ and mounting capacitance is 2pF . Calculate its series and parallel resonating frequencies.

21. Calculate the frequency of oscillation for the clap oscillator with $C_1=0.1\mu\text{F}$, $C_2=1\mu\text{F}$, $C_3=100\text{pF}$ and $L=470\mu\text{H}$.