OSCILLATORS

→ A device which works on the principle of positive feedback and produces the sustained oscillations of constant frequency and amplitude is called an Oscillator.

→ An oscillator is a circuit which basically acts as a generator, generating the output signal which oscillates with constant amplitude and constant desired frequency.

→ An oscillator does not require any input signal.

→ An oscillator can generate the output waveform of high frequency upto gigahertz.

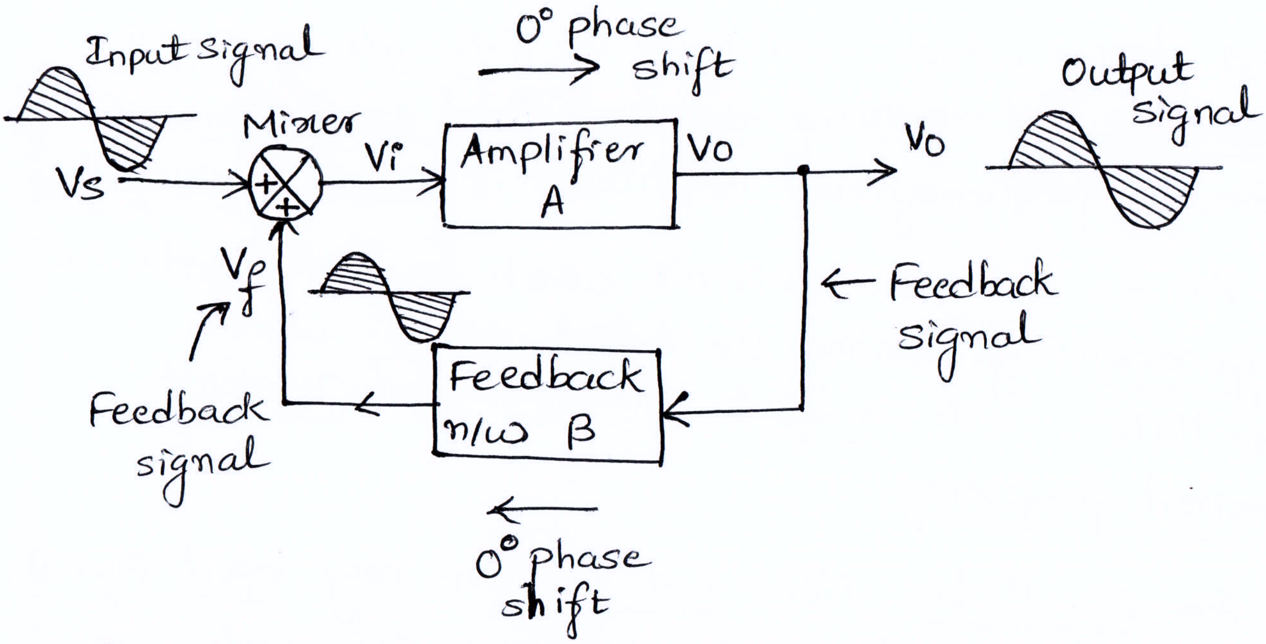
→ In short, an oscillator is an amplifier, which uses a positive feedback and without any external input signal, generates an output waveform at a desired frequency.

Concept of Positive Feedback.

→ The feedback is a property which allows to feedback the part of the output, to the same circuit as its input.

→ Such a feedback is said to be positive whenever the part of the output that is fed back to the amplifier as its input, is in phase with the original input signal applied to the amplifier.

→ Consider a non-inverting amplifier with the voltage gain A as shown below.



→ A non-inverting amplifier means there is no phase shift between its input and output.

→ Assume that a sinusoidal input signal, Vs is applied to the circuit.

→ As amplifier is non-inverting, the output voltage, Vo is in phase with the input signal, Vs.

→ The part of the output is fed back to the input with the help of a feedback network.

→ How much part of the output is fedback to be, gets decided by the feedback network gain, β.

→ No phase change is introduced by the feedback network. Hence the feedback voltage, Vf is in-phase with the input signal, Vs.

→ As the phase of the feedback signal is same as that of the input applied, the feedback is called positive feedback.

→ The amplifier gain is 'A' i.e., it amplifies its input V_i, 'A' times to produce output V_o,

$$\boxed{A = \frac{V_o}{V_i}}$$ This is called open loop gain of the amplifier.

→ For the overall circuit; the input is supply voltage, V_s and net output is V_o.

→ The ratio of output V_o to input V_s considering effect of feedback is called closed loop gain of the circuit or gain with feedback denoted as A_f.

$$\therefore \boxed{A_f = \frac{V_o}{V_s}}$$

→ The feedback is positive and voltage V_f is added to V_s to generate input of amplifier V_i, So referring fig above, we can write

$$\boxed{V_i = V_s + V_f} \longrightarrow (1)$$

→ The feedback voltage V_f depends on the feedback element gain β, So we can write,

$$\boxed{V_f = \beta V_o} \longrightarrow (2)$$

Substituting (2) in (1), we get

$$V_i = V_s + \beta V_o$$

$$\therefore \boxed{V_s = V_i - \beta V_o} \longrightarrow (3)$$

Substituting (3) in A_f, we get

$$A_f = \frac{V_o}{V_i - \beta V_o}$$

Dividing both numerator and denominator by V_i,

$$A_f = \frac{(V_o/V_i)}{1-\beta(V_o/V_i)}$$

$$\therefore \boxed{A_f = \frac{A}{1-\beta A}} \qquad \text{as } A = \frac{V_o}{V_i}$$

Now consider the various values of β, and the corresponding values of A_f for constant amplifier gain of $\boxed{A=20}$

A	β	A_f
20	0.005	22.22
20	0.04	100
20	0.045	200
20	0.05	∞

→ The above table shows that the gain with feedback increases as the amount of positive feedback increases.

→ In the limiting case, the gain becomes infinite.

→ This indicates that circuit can produce output without external input ($V_s = 0$), just by feeding the part of the output as its own input.

→ Similarly, the output cannot be infinite but gets driven into the oscillations. In other words, the circuit stops amplifying and starts oscillating.

→ Thus without an input, the output will continue to oscillate whose frequency depends upon the feedback network or the amplifier or both. Such a circuit is called as an oscillator.

→ It must be noted that β the feedback network gain is always a fraction and hence $\boxed{\beta < 1}$.

→ So the feedback network is an attenuation network.

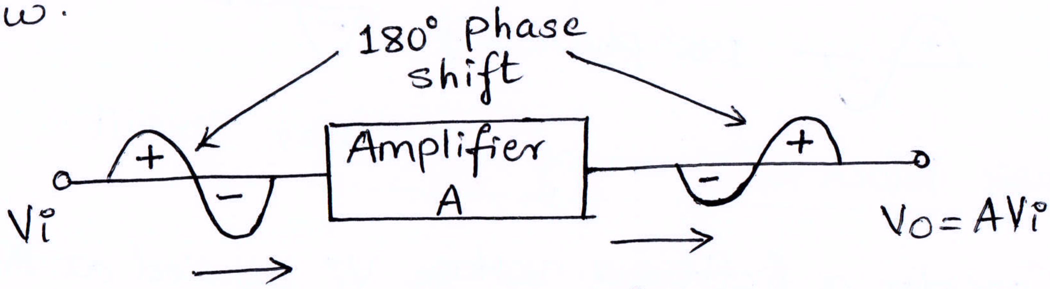
→ To start with the oscillations $A\beta > 1$ but the circuit adjusts itself to get $A\beta = 1$, when it provides sinusoidal oscillations while working as an oscillator.

→ Thus an oscillator is an amplifier, which uses a positive feedback and without any external input signal, generates an output waveform, at a desired frequency.

Barkhausen Criterion.

→ Consider a basic inverting amplifier with an open loop gain 'A'.

→ As basic amplifier is inverting, it produces a phase shift of 180° between input and output as shown below.



Inverting Amplifier

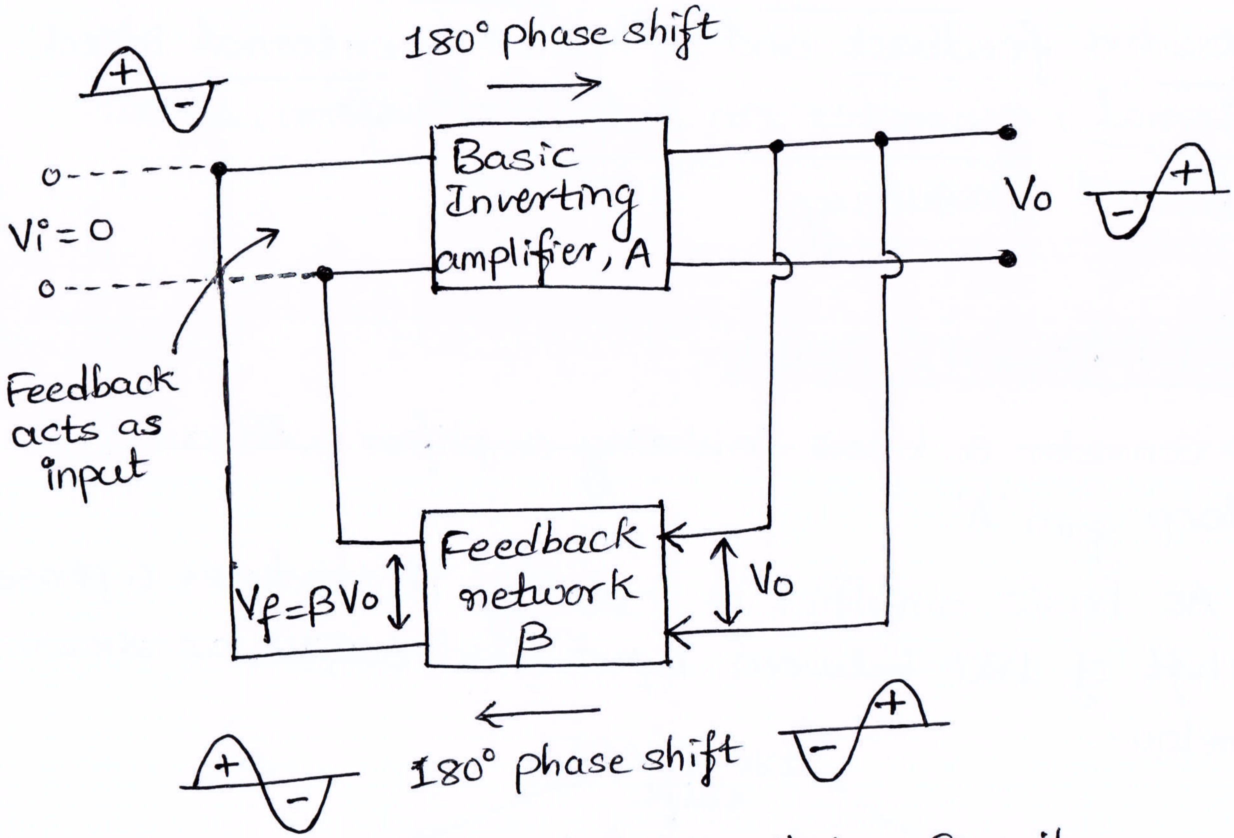
→ The feedback network attenuation factor β is less than unity.

→ Now the input Vi applied to the amplifier is to be derived from its output Vo using feedback network.

→ But the feedback must be positive i.e; the voltage derived from output using feedback network must be in phase with V_i.

→ Thus the feedback network must introduce a phase shift of 180° while feeding back the voltage from output to input.

→ This ensures positive feedback. The arrangement is shown below.



Basic Block diagram of Oscillator Circuit.

→ Consider a fictitious voltage V_i applied at the input of the amplifier. Hence we get

$$\boxed{V_o = AV_i} \longrightarrow (1)$$

→ The feedback facter β decides the feedback to be given to input,

$$\boxed{V_f = \beta V_o} \longrightarrow (2)$$

→ Substituting (1) in (2), we get,

$$\boxed{V_f = A\beta V_i} \longrightarrow (3)$$

→ For the oscillator, we want that feedback should drive the amplifier and hence V_f must act as V_i.

→ from (3) we can write that, V_f is sufficient to act as V_i when, $\boxed{|A\beta| = 1}$

→ The phase of V_f is same as V_i i.e., feedback n/w should introduce 180° phase shift in addition to 180° phase shift introduced by inverting amplifier. This ensures positive feedback. So total phase shift around a loop is 360°.

→ In this connection, V_f drives the circuit and without external input, circuit works as an oscillator.

→ The two conditions discussed above, required to work the circuit as an oscillator are called 'Barkhausen Criterion' for oscillator.

The Barkhausen Criterion states that:

1) The total phase shift around a loop, as the signal proceeds from input through amplifier, feedback network back to input again, completing a loop, is precisely $\boxed{0° \text{ or } 360°}$.

2) The magnitude of the product of the open loop gain of the amplifier (A) and the magnitude of the feedback factor (β) is unity ie, $\boxed{|A\beta| = 1}$

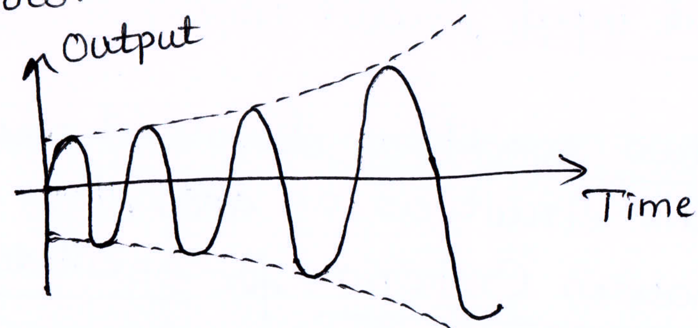
Satisfying these conditions, the circuit works as an oscillator producing sustained oscillations of constant frequency and amplitude.

Effect of $A\beta$ on the Nature of the Oscillations.

1) $|A\beta| > 1$

→ When the total phase shift around the loop is 0° or 360° and $|A\beta| > 1$, then the output oscillates but the oscillations are of growing type.

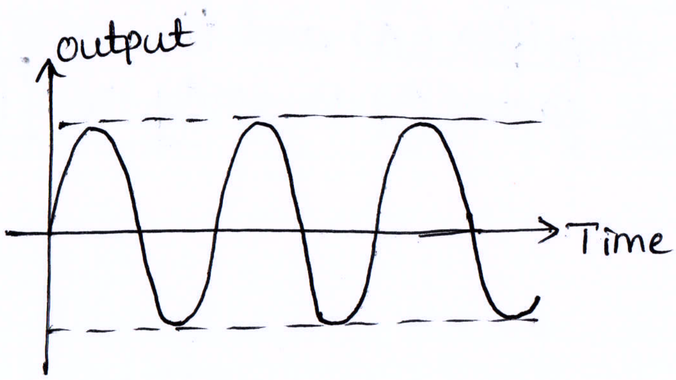
→ The amplitude of oscillations goes on increasing as shown below.



Growing type Oscillations.

2) $|A\beta| = 1$

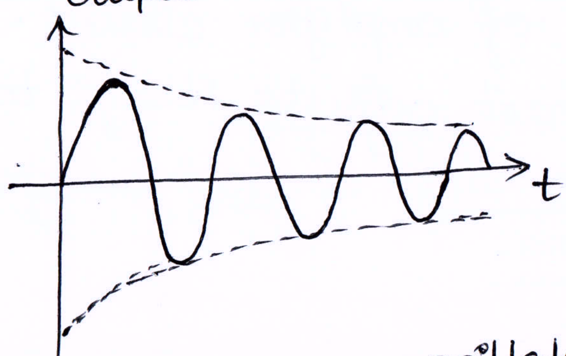
→ When total phase shift around a loop is 0° or 360° ensuring positive feedback and $|A\beta| = 1$ then the oscillations are with constant frequency and amplitude called Sustained oscillations. as shown below



Sustained Oscillations.

3) $|A\beta| < 1$

→ When total phase shift around a loop is $0°$ or $360°$ but $|A\beta| < 1$ then the oscillations are of decaying type i.e., such oscillation amplitude decreases exponentially and the oscillations finally cease as shown below.



Exponentially Decaying oscillations.

→ So, to start the oscillations without input, $|A\beta|$ is kept higher than unity and then circuit adjusts itself to get $|A\beta| = 1$ to result sustained oscillations.

Starting Voltage.

→ It is mentioned that no external input is required in case of oscillators.

→ Every resistance has some free electrons.

→ Under the influence of normal room temperature, these free electrons move rapidly in various directions. Such a movement of free electrons generate a voltage called noise voltage, across the resistance.

→ Such noise voltages present across the resistances are amplified.

→ Hence to amplify such small noise voltages and to start the oscillations, $|A\beta|$ is kept greater than unity at start. Such amplified voltage appears at the output terminals.

→ The part of this output is sufficient to drive the input of amplifier circuit.

→ Then circuit adjusts itself to get $|A\beta| = 1$ and with phase shift of 360° we get sustained oscillations.

Classification of Oscillators.

OSCILLATORS

- Based on Output Waveform
  - Triangular
  - Rectangular
  - Sinusoidal
- Based on Circuit Component
  - R&C
  - Crystal
  - C&L
- Based on range of frequency
  - R-C Low frequency 20Hz – 200kHz
  - L-C High frequency > 300kHz
- Based on type of feedback
  - UJT relaxation Oscillator in which feedback is not used

BJT as an Oscillator.

LC Oscillators.

→ The oscillators which use the elements L and C to produce the oscillations are called LC Oscillators.

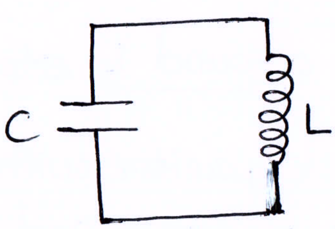
→ The circuit using elements L and C is called Tank Circuit or Oscillatory Circuit, which is an important part of LC Oscillators.

→ This circuit is also referred as resonating circuit or tuned circuit.

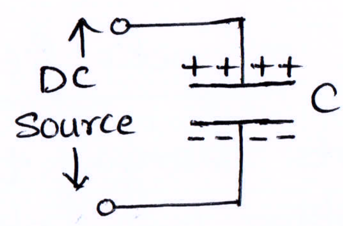
Operation of LC Tank Circuit

→ The LC tank circuit consists of elements L and C connected in parallel as shown below.

→ Let capacitor is initially charged from a dc source with the polarities as shown below.



LC tank circuit



Initial charging

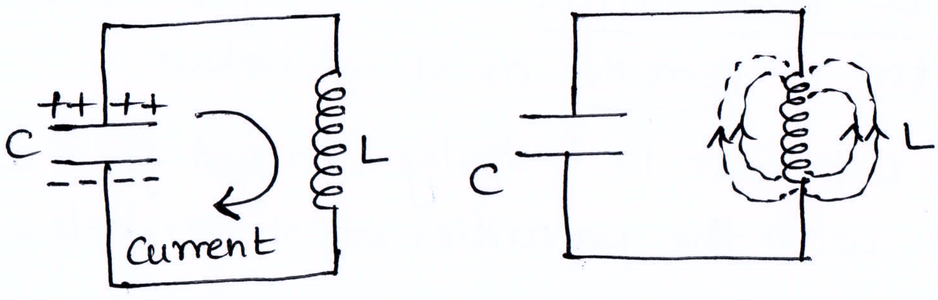
→ When the capacitor gets charged, the energy gets stored in a capacitor called Electrostatic energy.

→ When such a charged capacitor is connected across inductor, L in a tank circuit, the capacitor starts discharging through L a shown below.

→ The arrow indicates direction of flow of conventional current.

→ Due to such current flow, the magnetic field gets set up around the inductor, L. Thus inductor starts storing the energy.

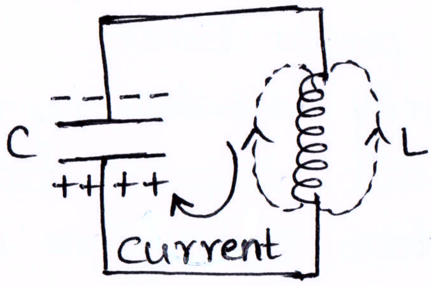
→ When capacitor is fully discharged, maximum current flows through the circuit. At this instant all the electrostatic energy get stored as a magnetic energy in the inductor L as shown below.

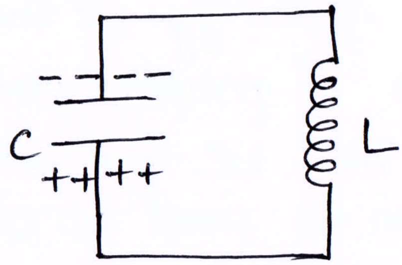


→ Now the magnetic field around L starts collapsing.

→ This starts charging the capacitor with opposite polarity making lower plate positive and upper plate negative as shown below.

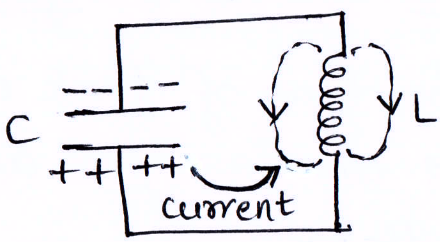
→ After some time, capacitor gets fully charged with opposite polarities, as compared to its initial polarities as shown below. The entire magnetic energy gets converted back to electrostatic energy in capacitor.





→ Now capacitor again starts discharging through inductor, L. But the direction of current through circuit is now opposite to the direction of current earlier in the circuit as shown below.

→ Again electrostatic energy is converted to magnetic energy. When capacitor is fully discharged, the magnetic field starts collapsing, charging the capacitor again in opposite direction.



→ Thus capacitor charges with alternate polarities and discharges producing alternating current in the tank circuit. This is nothing but oscillatory current.

→ But everytime when energy is transferred from C to L and L to C, the losses occur due to which amplitude of oscillating current keeps on decreasing everytime when transfer takes place.

→ Hence actually we get exponentially decaying oscillations called Damped Oscillations.

→ Such oscillations stop after sometime.

→ In LC Oscillator, the transistor amplifier supplies this loss of energy at the proper times.

→ The care of proper polarity is taken by the feedback network. Thus LC tank circuit alongwith transistor amplifier can be used to obtain oscillators called LC oscillators.

→ Due to supply of energy which is lost, the oscillations get maintained hence called Sustained oscillations or Undamped oscillations.

→ The frequency of oscillations generated by LC tank circuit depends on the values L and C and is given by

$$\boxed{f = \frac{1}{2\pi\sqrt{LC}} \ \text{Hz}}$$

where L is in Henries and C is in farads.

→ Depending upon the type of tank circuit used, the LC oscillators are classified as

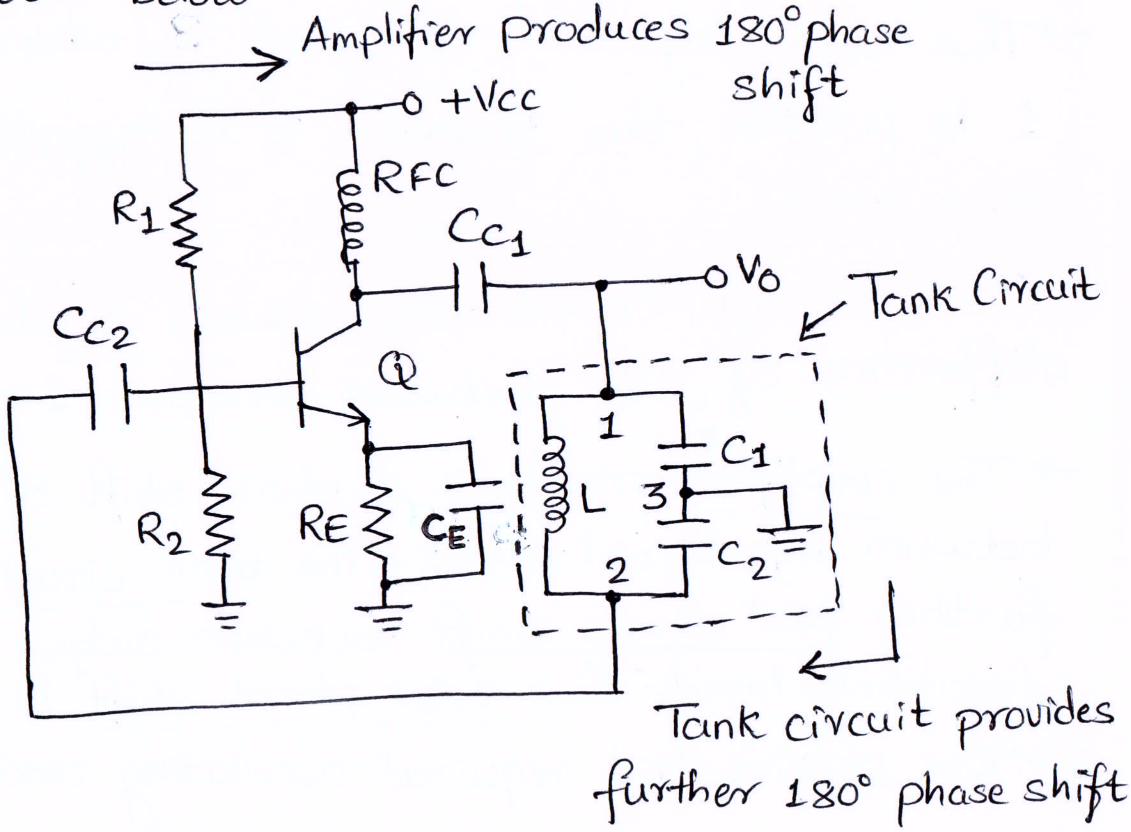
1) Colpitt's Oscillator
2) Hartley Oscillator.

COLPITT'S OSCILLATOR

→ The tank circuit of Colpitt's oscillator uses two capacitors and one inductor.

→ The two capacitors are C_1 and C_2 which are connected in series across the inductor L to complete the tank circuit.

→ The circuit of transistorised Colpitt's oscillator is shown below.



→ The amplifier stage uses an active device as a transistor in CE configuration.

→ The R_1 and R_2 are the biasing resistances.

→ The RE is the stabilisation resistances.

→ The C_{C1} and C_{C2} are the coupling capacitors.

→ The capacitive divider C_1 and C_2 in the tank circuit provides the necessary feedback for oscillations

→ The RFC is radio frequency choke due to which the isolation between ac and dc operation is achieved.

→ When the supply is switched on, the oscillatory current is set up in the tank circuit.

→ It produces ac voltages across C_1 and C_2.

→ The terminal 3 is grounded hence it is at zero potential.

→ Thus with respect to terminal 3, when terminal 1 is positive, the terminal 2 is negative and vice versa.

→ Thus at any instant there exists a phase difference of 180° between terminals 1 and 2.

→ The amplifier produces a phase shift of 180° between input and output. The tank circuit adds further 180° phase shift between output and feedback input. Thus total phase shift is 360°.

→ This satifies the required oscillating conditions.

→ The frequency of oscillations produced by Colpitt's Oscillator is given by

$$\boxed{f = \frac{1}{2\pi\sqrt{LC_{eq}}}}$$

where $C_{eq} = \dfrac{C_1 C_2}{C_1 + C_2}$, equivalent capacitance

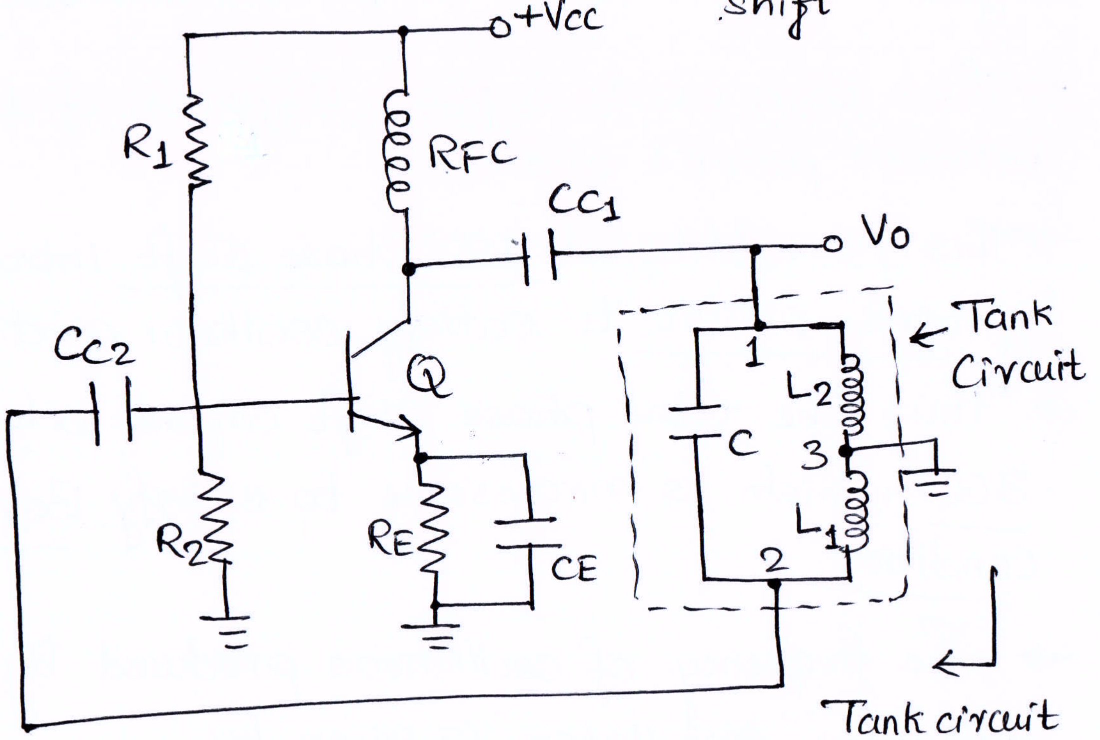
HARTLEY OSCILLATOR

→ This is another LC oscillator which uses two inductors and one capacitor. in its tank circuit.

→ The two inductors are L_1 and L_2 which are connected in series across the capacitor C to complete the tank circuit.

→ The circuit of transistorised Hartley Oscillator is shown below

→ Amplifier produces 180° phase shift



Tank circuit provides further 180° phase shift.

→ The resistances R_1, R_2 and R_E provide necessary bias to the circuit.

→ The capacitors C_{c1} and C_{c2} are coupling capacitors.

→ The feedback network consists of the tank circuit made up of two inductors L_1 and L_2 and Capacitor C.

→ The RFC is used to achieve isolation between ac and dc conditions.

→ The transistor amplifier provides a phase shift of 180°.

→ When Vcc is switched on, the capacitor C gets charged and oscillatory current is set up in the tank circuit.

→ As the point 3 is earthed, when point 1 is positive then at the same instant point 2 is negative with respect to point 3 and vice versa.

→ Thus there exists a phase difference of 180° between point 1 and 2.

→ This is additional 180° phase shift introduced by tank circuit to satisfy oscillator condition.

→ Thus the total phase shift around a loop is 360° which is necessary to satisfy Barkhausen Condition.

→ The frequency of oscillations produced by Hartley Oscillator is given by

$$\boxed{f = \frac{1}{2\pi\sqrt{L_{eq}C}}}$$

where $L_{eq} = L_1 + L_2$, equivalent inductor.

Numericals.

1) In a colpitt's oscillator, $C_1 = C_2 = C$ and $L = 100\mu H$. The frequency of oscillations is $500 KHz$. Determine 'C'.

Solⁿ: $L = 100\mu H$, $f = 500 KHz$, $C_1 = C_2 = C$

$$f = \frac{1}{2\pi\sqrt{LC_{eq}}}, \quad 500KHz = \frac{1}{2\pi\sqrt{100\mu H \times C_{eq}}}$$

$$(500 \times 10^3)^2 = \frac{1}{4\pi^2 \times 100 \times 10^{-6} \times C_{eq}}$$

$$\therefore \boxed{C_{eq} = 1.0132 \times 10^{-9} F}$$

but $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$ & $C_1 = C_2 = C$

$$\therefore C_{eq} = \frac{C^2}{2C} = \frac{C}{2}$$

$$\therefore 1.0132 \times 10^{-9} = \frac{C}{2}$$

$$\therefore C = 2 \times 1.0132 \times 10^{-9} = 2.026 \times 10^{-9} F$$

$$= \boxed{2.026 nF}.$$

2) Design the value of an inductor to be used in Colpitt's Oscillator to generate a frequency of 10MHz. The circuit is used a value of $C_1 = 100pF$ and $C_2 = 50pF$.

Solⁿ: $C_1 = 100pF$, $C_2 = 50pF$, $f = 10MHz$.

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{100pF \times 50pF}{100pF + 50pF} = \boxed{33.33 \times 10^{-12} F}$$

$$f = \frac{1}{2\pi\sqrt{L C_{eq}}}, \quad 10 \times 10^6 = \frac{1}{2\pi\sqrt{L \times 33.33 \times 10^{-12}}}$$

$$(10\times10^{6})^2 = \frac{1}{4\pi^2 \times L \times 33.33\times10^{-12}}$$

$$L = \frac{1}{4\pi^2(10\times10^{6})^2(33.33\times10^{-12})}$$

$$\therefore \boxed{L = 7.6\times10^{-6} = 7.6\mu H}$$

3) Calculate the frequency of oscillations of Colpitt's oscillator having $C_1 = 2000pF$, $C_2 = 1000pF$ and $L = 4mH$. What should be the value of L if the frequency of oscillator is 140 KHz.

Soln: $C_1 = 2000pF$, $C_2 = 1000pF$, $L = 4mH$, $f' = 140 kHz$.

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{2000pF \times 1000pF}{2000pF + 1000pF} = \boxed{666.666\times10^{-12}F}$$

$$\therefore f = \frac{1}{2\pi\sqrt{L C_{eq}}} = \frac{1}{2\pi\sqrt{4\times10^{-3}(666.666\times10^{-12})}}$$

$$\therefore \boxed{f = 97.4621 KHz}$$

The new frequency $f' = 140 KHz$ with new inductance L'

$$\therefore f' = \frac{1}{2\pi\sqrt{L' C_{eq}}} = (f')^2 = \frac{1}{4\pi^2 \times L' \times C_{eq}}$$

$$\therefore L' = \frac{1}{4\pi^2 \times (f')^2 \times C_{eq}} = \frac{1}{4\pi^2 \times (140\times10^{3})^2 \times 666.666\times10^{-12}}$$

$$\therefore \boxed{L' = 1.9385 mH}$$

4) In a Colpitt's oscillator, if the desired frequency is 800 kHz, Determine the values of 'L' and 'C'.

Soln. $f = 800\,kHz$.

Assume/Choose $\boxed{C_1 = C_2 = 1000\,pF}$

$\therefore C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \boxed{500\,pF}$

Now, $f = \frac{1}{2\pi\sqrt{L C_{eq}}}$ i.e., $800 \times 10^3 = \frac{1}{2\pi\sqrt{L \times 500 \times 10^{-12}}}$

$\therefore \boxed{L = 79.1571\,\mu H}$

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5) Calculate the frequency of oscillations of a Hartley oscillator having $L_1 = 0.5\,mH$, $L_2 = 1\,mH$ and $C = 0.2\,\mu F$.

Soln: $L_1 = 0.5\,mH$, $L_2 = 1\,mH$, $C = 0.2\,\mu F$

Now, $f = \frac{1}{2\pi\sqrt{L_{eq} C}}$

$L_{eq} = L_1 + L_2 = 0.5\,mH + 1\,mH = \boxed{1.5\,mH}$

$\therefore f = \frac{1}{2\pi\sqrt{1.5 \times 10^{-3} \times 0.2 \times 10^{-6}}} = \boxed{9.19\,kHz}$

6) In a Hartley oscillator, $L_1 = 20\,\mu H$, $L_2 = 2\,mH$, and C is variable. Find the range of C if frequency is to be varied from 1 MHz to 2.5 MHz. Neglect mutual inductance.

Soln: $L_1 = 20\,\mu H$, $L_2 = 2\,mH$, $f_{max} = 2.5\,MHz$, $f_{min} = 1\,MHz$.

PTO

$$L_{eq} = L_1 + L_2 = \boxed{2.002 \times 10^{-3}\, H}$$

for $f = f_{max} = 2.5\,MHz$.

$$f_{max} = \frac{1}{2\pi\sqrt{L_{eq} \cdot C}}, \quad \boxed{C = 2.0244\,pF}$$

for $f = f_{min} = 1\,MHz$.

$$f_{min} = \frac{1}{2\pi\sqrt{L_{eq} \cdot C}}, \quad \boxed{C = 12.6525\,pF}$$

Thus C must be varied from 2.0244pF to 12.6525pF

7) Calculate the frequency of oscillations of the Hartley Oscillator which has $L_1 = 0.5\,mH$, $L_2 = 1\,mH$ and $C = 0.2\,\mu F$. What should be the value of C, if the frequency of oscillation were to be 12kHz with other components of the circuit intact?

Solⁿ:

$$L_{eq} = L_1 + L_2 = 0.5\,mH + 1\,mH$$
$$= \boxed{1.5\,mH}$$

$$\therefore f = \frac{1}{2\pi\sqrt{L_{eq} \times C}} = \frac{1}{2\pi\sqrt{1.5\times10^{-3} \times 0.2\times10^{-6}}}$$
$$= \boxed{9.19\,kHz}$$

Now, $f = 12\,kHz$

$$\therefore (12\times10^3)^2 = \frac{1}{4\pi^2 \times 1.5\times10^{-3} \times C}$$

$$\therefore \boxed{C = 0.1172\,\mu F}$$