Sinusoidal Oscillators

An oscillator is a device generating sinusoidal or non-sinusoidal wave forms without the application of an external input signal. An oscillator transforms *d.c.* power from the source into *a.c.* power in the load *i.e.*, its functioning is opposite to that of a rectifier.

Number of ways are used to classify the oscillators. Usually following ways are employed to categorise the oscillators :

(*i*) Based on generated wave form

(*ii*) Based on the components producing oscillators

(*iii*) Based on the generated frequency range.

(*i*) Classification based on generated wave form :

(*a*) **Sinusoidal or harmonic oscillators.** These oscillators generate the sinusoidal wave forms of definite frequencies.

(*i*) Negative Resistance Oscillators

(*ii*) Feedback Oscillators

(*iii*) Crystal Oscillatiors

(*b*) **Relaxation Oscillators.** Oscillators generating the non-sinusoidal wave forms *i.e.*, square or sawtooth wave forms, are called relaxation oscillators.

(*i*) Multivibrators

(*ii*) Saw Tooth wave generator

(*iii*) Square wave generator

(*ii*) Classification based on the components. This type of classification is based upon the property of the component or the device used to produce the oscillations. There are two types of such oscillators :

(*a*) **Negative resistance oscillators.** An oscillator having some active device whose current voltage characteristics exhibits a negative slope region for some part of its operation, is called the negative resistance oscillator. *e.g.*, the tunnel diode oscillator is a negative resistance oscillator.

(*b*) **Feedback oscillators.** A oscillator containing a positive feedback amplifier such that overall gain of the amplifier is infinite, is called the feedback oscillator.

Classification of feedback Oscillators

Feedback oscillators can be of two types :

(*a*) **LC-oscillators.** Using the inductor-capacitor components. *e.g.*, Tuned collector oscillator, Hartley oscillator and Colpitt oscillator.

(*b*) **RC-oscillators.** Using resistance capacitor components. *e.g.*, Phase-shift oscillator and Wien-bridge oscillator.

(*iii*) Classification based on the generated frequency range. Oscillators are grouped on the basis of generated frequency range.

	Types of oscillator	Generated frequency range
(*a*)	Audio frequency (AF)	20 – 20,000 Hz
(*b*)	Radio frequency (RF)	20,000 – 30 MHz
(*c*)	Very high frequency (VHF)	30 MHz – 300 MHz
(*d*)	Ultra high frequency (UHF)	300 MHz – 3 GHz
(*e*)	Microwave range	3 GHz – several GHz

Principle of oscillators. In an ordinary oscillating system, the amplitude of generated oscillations decays with time due to dissipation of energy by the resistance contained in the oscillator circuit.

The oscillations of undamped amplitude can be generated by compensating the amount of dissipated energy if a negative resistance is incorporated in the circuit to feedback the required energy.

Thus, to produce undamped oscillations, an oscillator must have the incorporated negative resistance. *e.g.*, In feedback oscillators, external positive feedback incorporates the negative resistance to make the overall gain infinite.

And in negative resistance oscillators, internal positive feedback incorporates the negative resistance.

Transistor as an Oscillator:

An oscillator is a device in which electrical oscillations (of voltages and currents) are produced without maintaining any external source. Input voltage required in such a self sustained oscillations is obtained from the output voltage of an amplifier. Thus an oscillator is a feed-back amplifier. A block diagram of such an amplifier is shown in fig. 1(a) and the circuit diagram of the oscillator shown in the fig. 1(b).

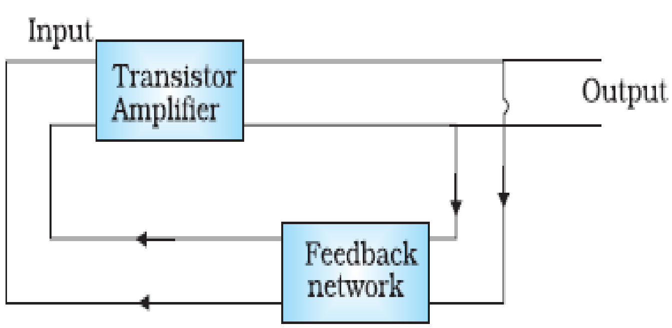


Fig. 1(a)

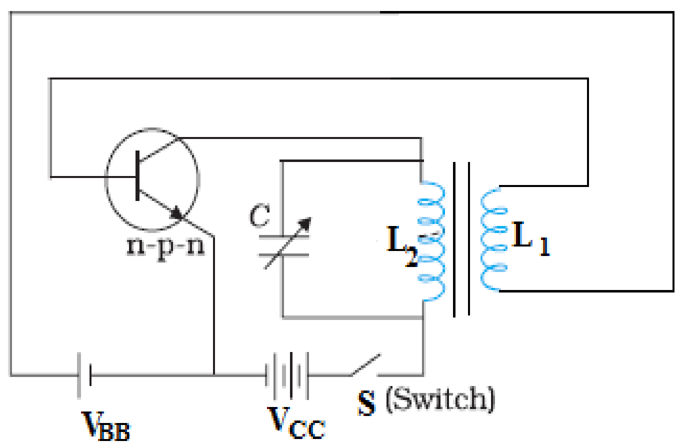


Fig. 1(b)

In the circuit diagram L_1 and L_2 are two coils wound on the same core and hence are inductively coupled through their mutual inductance. The coil L_2 is connected parallel to a capacitor C and this combination is called a tank circuit. The tank circuit is connected to the collector side. Therefore it is known as tuned collector oscillator. If the tank circuit is on the base side, it is known as tuned base oscillator.

Working

When the switch S is closed due to the biasing voltage V_{CC} the collector current begins to flow. This current increases slowly due to the inductance coil L_2. The inductive coupling between the coils L_1 and L_2 now causes a current to flow in the emitter circuit. As a result of this positive feedback also current in L_2 increases and at a certain instant attains a saturation value i.e., there will be no further increase of magnetic field in L_2 as a result of which the current and the magnetic field in L_1 begins to fall. Consequently the collector current will also fall and the magnetic field produced by L_2 falls after attaining the maximum value. The decrease of magnetic energy in the coil results in increase of electrical energy stored in the capacitor. In this way electrical oscillations take place in the tank circuit. The frequency of this oscillator is equal to the frequency of the tank circuit which is equal to

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

Feedback Requirement for Oscillator i.e. Barkhausen Criterion:

Let us first see the effect of feedback on amplifier gain. A feedback amplifier consists of a basic or internal amplifier and a feedback network as shown in figure.

The internal gain of the amplifier without feedback,

$$A = \frac{V_o}{V_i} \qquad ...(29)$$

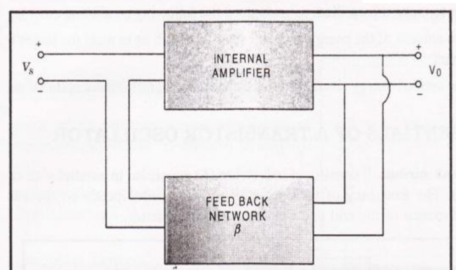


Fig. 3.14. Block diagram of feed back amplifier.

Let 'β' represents the feedback fraction or feedback ratio.

$\therefore$ A feedback network extracts a portion from the output voltage V_0 of the amplifier.

i.e. $\qquad V_f = \beta V_o \qquad ...(30)$

(This voltage will be fed to input)

$\therefore$ If V_s is the applied input signal voltage, then the input to the basic amplifier will be,

$$V_i = V_s \pm V_f$$

where + ve sign for the + ve feed back and – ve sign for the – ve feedback.

Let us assume that V_f is added in phase with V_s *i.e.* +ve feedback.

$$\therefore \qquad V_i = V_S + V_f$$

$\therefore$ From Eqn. (29) $\qquad V_o = AV_i$

$$= A(V_s + V_f) \qquad ...(31)$$

Substituting for V_f from Eqn. (30) in the above equation, we get,

$$V_0 = A\,(V_s + \beta V_o)$$

$$\Rightarrow \qquad V_o - A\beta V_o = AV_s$$

$$V_o\,(1 - A\beta) = AV_s$$

$$\Rightarrow \qquad \frac{V_o}{V_s} = \frac{A}{1 - A\beta} \qquad ...(32)$$

Now overall gain with feedback is

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

$$\Rightarrow \qquad A_f = \frac{A}{1 - A\beta} \qquad ...(33)$$

The factor $A\beta$ is called *"loop gain"* or *"return ratio"* or *"feedback factor"*.

From Eqn. (33), we see that

if $$A\beta = 1$$

$$\Rightarrow A_f = \infty$$

Since $$A_f = \frac{V_o}{V_s} \Rightarrow V_s = 0.$$

Then the amplifier delivers an output even with zero input voltage, *i.e.* the amplifier becomes an oscillator. The condition for unity loop gain is

$$A\beta = 1$$

This condition for loop gain is known as **"Barkhousen's criterion"** for oscillation.

∴ The basic conditions for oscillations in a feedback amplifier are :

(*i*) The magnitudes of loop gain must be equal to unity *i.e.* $|A\beta| = 1$.

(*ii*) The feed back must be regenerative type (+ ve feedback) *i.e.* the phase shift around a loop must be zero, or any integral multiple of 2π.

1. Tuned Collector Oscillator

This oscillator is called tuned collector oscillator as it contains a tuned LC circuit (tank circuit) connected to collector.

The combination of L and variable capacitor C form an oscillatory circuit to set up frequency of oscillator of = $\frac{1}{2\pi\sqrt{LC}}$. Coil L_1 is called feed back coil as it feeds back a portion of output to the input of transistor (by mutual induction) for amplification and to cover up the losses. It acts as secondary of the transformer. As transistor is connected in CE configuration, so it provides a phase shift of 180° between its input and output. Another phase shift of 180° is provided by transformer. In this way a phase shift of 360° appears between input and output voltages resulting in positive feedback. Supply voltage V_{CC}, emitter resistance R_e and potential dividing arrangement of R_1 and R_2 are used to set d.c. operating point. The capacitors C_1 and C_e are used to provide low

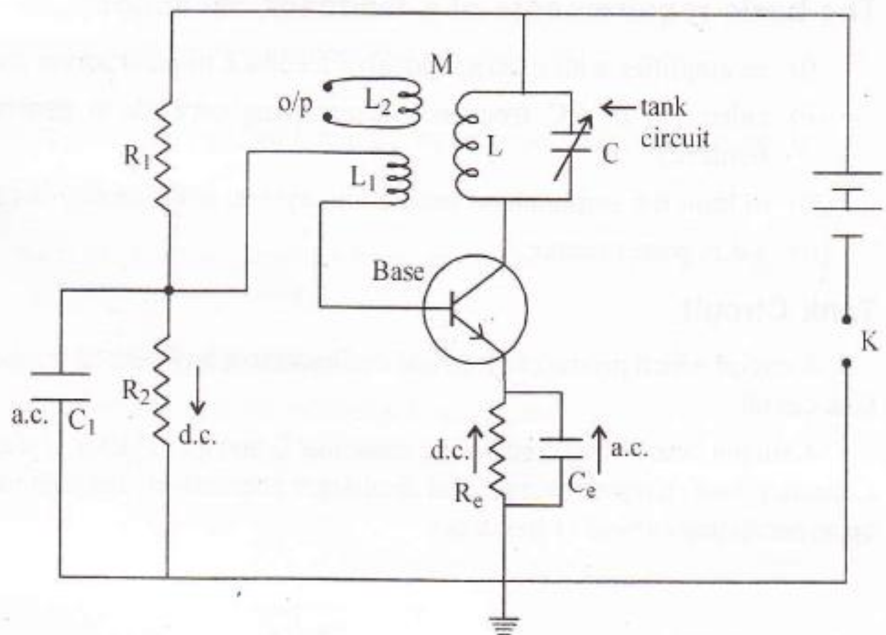


Fig. 9.1. Circuit diagram of a tuned collector oscillator.

Working :

Step 1 : When key K is closed, collector current starts increasing and charges the capacitor C.

Step 2 : When the capacitor C is fully charged, it discharges through coil L and sets up oscillators of frequency.

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \ldots (9.5)$$

Step 3 : These oscillations induce some voltage in coil L_1 by mutual induction. The frequency of this induced voltage is same as that of tank circuit but it's magnitude depends upon the number of turns of L_1 and coupling between L and L_1. This (a.c.) voltage across L_1 is applied between base and emitter and gets amplified after passing through transistor and appears at collector after amplification. So the losses occuring in the tank circuit are overcome and sustained osillations are obtained via L_2.

Derivation of Frequency and Condition for Sustained Oscillations

h-parametor equivalent circuit of oscillator is given below.

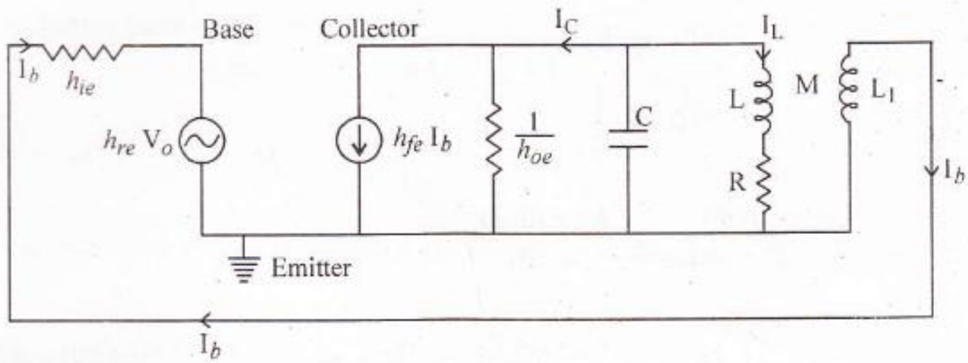


Fig. 9.2

Let Z_1 be the combined impedance of L and R.

$$= R + j\omega L \quad \ldots (9.6)$$

Let Z_L = equivalent impedance of capacitor reactance $\frac{1}{j\omega C}$ and Z_1 which are in parallel

$$\frac{1}{Z_L} = \frac{1}{1/j\omega C} + \frac{1}{R+j\omega L} = j\omega C + \frac{1}{R+j\omega L}$$

$$\frac{1}{Z_L} = \frac{j\omega RC - \omega^2 LC + 1}{R + j\omega L}$$

$$\Rightarrow \quad Z_L = \frac{R + j\omega L}{1-\omega^2 LC + j\omega RC} \quad \ldots(9.7)$$

Also voltage gain of CE transistor in terms of h-parameters as per eq. 5.73, (changing R_L to Z_L) is

$$A_V = -\frac{h_{fe} Z_L}{h_{ie} + \Delta h Z_L} \quad \text{where} \quad \Delta h = h_{ie}\, h_{oe} - h_{fe}\, h_{re} \quad \ldots (9.8)$$

According to Barkhausen Criterion for sustained oscillations $|A\beta| = 1$ ...(9.9)

To apply this condition, we need to find β.

$$\text{Now } \beta = \text{feedback fraction} = \frac{\text{feedback voltage}}{\text{Total output voltage}}$$

Here $\beta = \dfrac{\text{Voltage induced in coil } L_1 \text{ by mutual inductance (Secondary coil)}}{\text{Total output voltage across L (Primary coil)}}$

$$= -\frac{j\omega M \times I_L}{(R + j\omega L) \times I_L}$$

$$\beta = \frac{j\omega M}{R + j\omega L} \qquad \text{...(9.10)}$$

using $|A\beta| = 1$

$\Rightarrow$ $$|\beta| = \frac{1}{|A|}$$

i.e., $$\frac{j\omega M}{R + j\omega L} = \frac{h_{ie} + \Delta h\, Z_L}{h_{fe}\, Z_L}$$

$$\left(\frac{j\omega M}{R + j\omega L}\right) h_{fe} = \frac{h_{ie} + \Delta h\, Z_L}{Z_L} = \frac{h_{ie}}{Z_L} + \Delta h \qquad \text{... (9.11)}$$

Substituting the value of Z_L from 9.7 in 9.11

$$\frac{j\omega M\, h_{fe}}{R + j\omega L} = h_{ie}\left[\frac{1 - \omega^2 LC + j\omega RC}{R + j\omega L}\right] + \Delta h$$

$\Rightarrow$ $$j\omega M h_{fe} = h_{ie}\,[1 - \omega^2 LC + j\omega RC] + \Delta h[R + i\omega L] \qquad \text{...(9.12)}$$

Separating real and imaginary parts

$$j\omega M h_{fe} = h_{ie} - \omega^2 h_{ie} LC + R\Delta h + j\omega[h_{ie} RC + L\Delta h] \qquad \text{... (9.13)}$$

Equating real and imaginary parts

$$h_{ie} - \omega^2 h_{ie}\, LC + R\Delta h = 0$$

$$\omega^2 h_{ie}\, LC = h_{ie} + R\Delta h$$

$$\omega^2 = \frac{h_{ie} + R\Delta h}{h_{ie} LC} = \frac{1}{LC}\left[1 + \frac{R\Delta h}{h_{ie}}\right]$$

$\Rightarrow$ $$\omega = \frac{1}{\sqrt{LC}}\left[1 + \frac{R\Delta h}{h_{ie}}\right]^{\frac{1}{2}} \qquad \text{...(9.14)}$$

$\Rightarrow$ Frequency of oscillations, $$f = \frac{1}{2\pi\sqrt{LC}}\left[1 + \frac{R\Delta h}{h_{ie}}\right]^{\frac{1}{2}} \qquad \text{...(9.15)}$$

For a coil having high quality factor Q, R is small, Δh is small and h_{ie} is large. For a coil having high quality factor Q, R is small and *hie* is large.

$\Rightarrow$ $\dfrac{R\Delta h}{h_{ie}}$ can be neglected

Hence,
$$f = \frac{1}{2\pi\sqrt{LC}}$$

Equating imaginary parts in Eq. 9.13.

$$\omega M h_{fe} = \omega\,[h_{ie}RC + L\Delta h]$$

$$\Rightarrow \qquad M = \frac{RCh_{ie} + L\Delta h}{h_{fe}} \qquad \ldots (9.16)$$

This equation gives the minimum value of the mutual inductance that should exist for oscillations to sustain.

2. Hartley Oscillator*

Hartley Oscillator is most frequently used and simple oscillator. It has two main advantages (*i*) It is adaptable to wide range of frequencies
(*ii*) Is very easy to tune.

It is of two types :

(*i*) Series fed Hartley oscillator

(*ii*) Shunt fed Hartley oscillator or Tuned Base Hartley.

Series fed Hartley has certain disadvantages which are removed in Shunt fed Hartley oscillator.

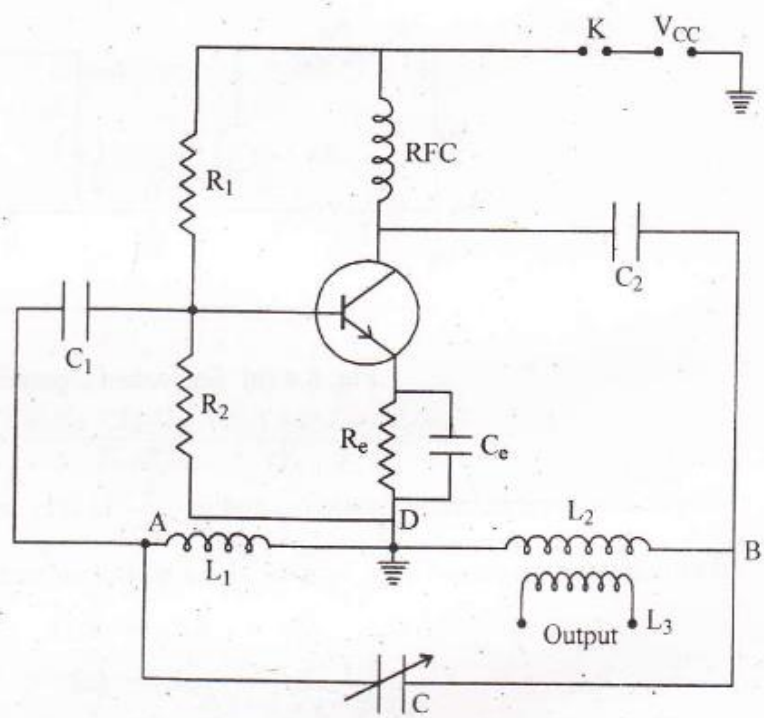


Fig. 9.3. Hartley Oscillator

Shunt fed Hartley Oscillator

In it's circuit, resistors R_1, R_2 and R_e and power supply V_{CC} are used to fix the d.c. operating point of the transistor. Variable capacitor C, inductors L_1 and L_2 fix the frequency of the oscillating circuit. Coils L_1 and L_2 are inductively coupled to each other. The coil L_1 also feeds back a fraction of the output voltage (that appears across L_2) to input of the transistor for amplification, to overcome the losses.

Capacitor C_2 block d.c. and provide low resistance path to a.c. which is amplified from collector to the tank circuit.

Radio frequency coil (RFC) provides d.c. bias to collector and it also prevents a.c. (oscillations) from reaching the d.c. supply V_{CC} . Similarly Capacitor C_1 and resistances R_1 and R_2 provide voltage divider self bias to the circuit and fix and stabilise the operating point. Capacitor C_e is used to give low resistance to a.c.

Working. When key K is closed, the capacitor is charged due to flow of current. When the capacitor C is fully charged, it discharges through coils L_1 and L_2 setting up oscillations of frequency.

$$f = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}} \qquad \ldots (9.17)$$

The output voltage of the amplifier appears across L_2 and feed back voltage across L_1. The voltage across L_1 is 180° out of phase with the voltage across L_2 (V_{output}).

Another Phase shift of 180° is produced by the transistor in addition to phase shift of 180° produced by $L_1 - L_2$ voltage divider so that a positive feedback with phase difference 360° is fixed for sustained undamped oscillations.

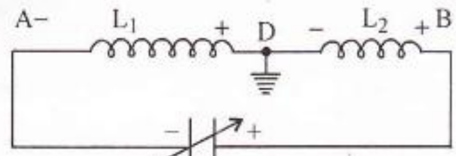


Fig. 8.4 (a)

Derivation of Frequency and Condition for Sustained Oscillators

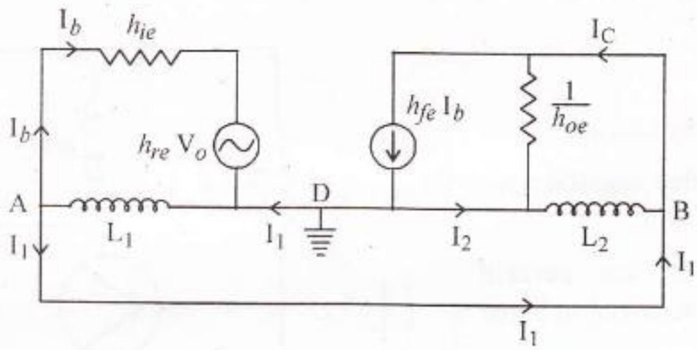


Fig. 8.4 (b) Equivalent L-parameter circuit

Neglecting reverse voltage ratio h_{re} and as $\frac{1}{h_{oe}}$ is very large and can be omitted.

Let inductive reactance of L_1 and L_2 along with their mutual inductance be written as

$$Z_1 = j\omega L_1 + j\omega M \quad \dots (9.18)$$

$$Z_2 = j\omega L_2 + j\omega M \quad \dots (9.19)$$

Let Z_3 = Capacitive reactance of capacitor C

$$Z_3 = \frac{1}{j\omega C} = -\frac{j}{\omega C} \quad \dots (9.20)$$

Replacing L_1, L_2 and C by equivalent impedances Z_1, Z_2 and Z_3, equivalent circuit becomes

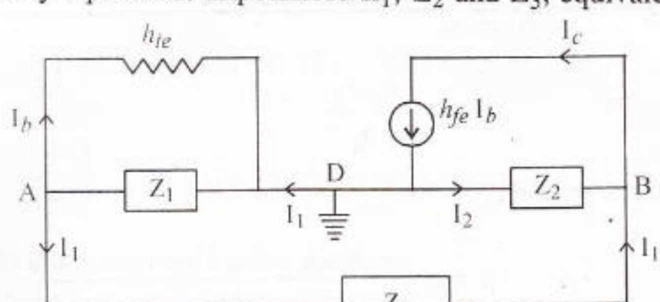


Fig. 8.4 (c)

To find expression for overall impedance Z_L :

The input resistance h_{ie} and impedance Z_1 are in parallel. Their equivalent impedance Z' is given by

$$\frac{1}{Z'} = \frac{1}{Z_1} + \frac{1}{h_{ie}} = \frac{h_{ie} + Z_1}{Z_1 h_{ie}}$$

$$\Rightarrow \qquad Z' = \frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \qquad \ldots (9.21)$$

This Z′ is in series with Z_3, so effective impedance $Z'' = Z' + Z_3$

This Z″ is in parallel with Z_2.

So the net load impedance Z_L between output terminals B and D is given by

$$\frac{1}{Z_L} = \frac{1}{Z''} + \frac{1}{Z_2} = \frac{1}{Z' + Z_3} + \frac{1}{Z_2} = \frac{1}{Z_2} + \frac{1}{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3}$$

$$= \frac{1}{Z_2} + \frac{Z_1 + h_{ie}}{Z_1 Z_3 + hie(Z_1 + Z_3)}$$

$$= \frac{Z_1 Z_3 + h_{ie}(Z_1 + Z_3) + Z_1 Z_2 + Z_2 h_{ie}}{Z_2(Z_1 Z_3 + h_{ie}(Z_1 + Z_3))}$$

$$\frac{1}{Z_L} = \frac{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3}{Z_2[Z_1 Z_3 + h_{ie}(Z_1 + Z_3)]}$$

$$\Rightarrow \qquad Z_L = \frac{Z_2[Z_1 Z_3 + h_{ie}(Z_1 + Z_3)]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \qquad \ldots (9.22)$$

To apply Barkhausen Criterion for sustained oscillations

$$A\beta = 1 \qquad \ldots (9.23)$$

We need to find A and β.

Now
$$A = -\frac{h_{fe} Z_L}{h_{ie} + \Delta h Z_L}$$

Neglecting Δh for CE configuration.

$$A = -\frac{h_{fe} Z_L}{h_{ie}} \qquad \ldots (9.24)$$

To find β the feedback fraction :

$$\beta = \frac{\text{feedback voltage between A and D}}{\text{Total output voltage between D and B}} = \frac{V_{fb}}{V_0} \qquad \ldots (9.25)$$

Now output voltage is voltage drop across Z_2 by current I_2 across it.

This voltage drop will be same as that across total impedance Z″ between terminals D and B by current I_1.

So
$$V_0 = -I_1 Z'' = -I_1(Z' + Z_3) \qquad \text{(See note)}$$

Also V_{fb} = Voltage drop between terminals D and A by current I_1

$$V_{fb} = -I_1 Z'$$

So from Eq. 9.25,

$$\beta = \frac{V_{fb}}{V_O} = \frac{I_1 Z'}{-I_1(Z'+Z_3)} = \frac{\dfrac{Z_1 h_{ie}}{Z_1 + h_{ie}}}{\dfrac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3}$$

$$\beta = \frac{Z_1 h_{ie}}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})} = \frac{Z_1 h_{ie}}{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)} \quad \dots (9.26)$$

Applying the condition, $A\beta = 1$

$$\left(\frac{h_{fe} Z_L}{h_{ie}}\right)\left(\frac{Z_1 h_{ie}}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})}\right) = 1$$

$$-\frac{h_{fe}}{h_{ie}} \frac{Z_2[Z_1 Z_3 + h_{ie}(Z_1 + Z_3)]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \times \frac{Z_1 h_{ie}}{[Z_1 Z_3 + h_{ie}(Z_1 + Z_3)]} = 1$$

$$\Rightarrow \; -h_{fe} Z_2 Z_1 = h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3$$

$$\Rightarrow \; h_{ie}(Z_1 + Z_2 + Z_3) + Z_2 Z_1 (1 + h_{fe}) + Z_1 Z_3 = 0 \quad \dots (9.27)$$

Substituting the values of Z_1, Z_2 and Z_3 in Eqn. (9.27)

$$h_{ie}\left[(j\omega L_1 + j\omega M) + (j\omega L_2 + j\omega M) - \frac{j}{\omega C}\right] + \left[(j\omega L_1 + j\omega M)(j\omega L_2 + j\omega M)(1 + h_{fe})\right]$$

$$+ \left[(j\omega L_1 + j\omega M)\left(-\frac{j}{(\omega C)}\right)\right] = 0$$

$$j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] + j^2\omega^2\left[(L_1 + M)(L_2 + M)(1 + h_{fe})\right] - j^2\left[\frac{L_1 + M}{C}\right] = 0$$

$$\Rightarrow j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] - \omega^2\left[(L_1 + M)(L_2 + M)(1 + h_{fe})\right] + \left[\frac{L_1 + M}{C}\right] = 0 \quad \dots (9.28)$$

Equating imaginary part

$$L_1 + L_2 + 2M - \frac{1}{\omega^2 C} = 0 \quad \dots (9.29)$$

$$\omega^2 C = \frac{1}{L_1 + L_2 + 2M} \;\Rightarrow\; \omega = \frac{1}{\sqrt{C(L_1 + L_2 + 2M)}}$$

$\Rightarrow$ Frequency of oscillation,

$$f = \frac{1}{2\pi\sqrt{C(L_1 + L_2 + 2M)}} \quad \dots (9.30)$$

To find condition for maintainance of oscillations equate real part of Eqn.9.29.

$$-\omega^2 (L_1 + M)(L_2 + M)(1 + h_{fe}) + \left(\frac{L_1 + M}{C}\right) = 0$$

$$\Rightarrow \quad (L_1 + M)\left[-\omega^2(L_2 + M)(1 + h_{fe}) + \frac{1}{C}\right] = 0$$

$$L_1 + M \neq 0$$

$$\Rightarrow \quad -\omega^2(L_2 + M)(1 + h_{fe}) + \frac{1}{C} = 0$$

$$\Rightarrow \quad 1 + h_{fe} = \frac{1}{C\omega^2(L_2 + M)}$$

Substituting, $\frac{1}{\omega^2 C} = L_1 + L_2 + 2M$ from Eqn.9.29.

$$1 + h_{fe} = \frac{L_1 + L_2 + 2M}{L_2 + M}$$

$$1 + h_{fe} = \frac{(L_1 + M) + (L_2 + M)}{L_2 + M} = 1 + \frac{L_1 + M}{L_2 + M}$$

$$\Rightarrow \quad h_{fe} = \frac{L_1 + M}{L_2 + M} \quad \ldots (9.31)$$

This is the condition of sustained oscillations in Hartley Oscillator. The condition can be met by simply changing the tapping point on the coil which will not disturb the frequency of oscillation because $L_1 + L_2$ will remain constant even by changing the tapping point.

RC Oscillators:

Two main commonly used RC oscillators are

1. Wien-bridge Oscillators
2. Phase shift Oscillators.

Wien Bridge Oscillator

It is a standard oscillator circuit for all low frequencies ranging from 5Hz to 1MHz.

This oscillator consists of two stage CE amplifier with a RC lead-lag network. The first stage of CE transistor serves as an oscillator and an amplifier while the second stage CE transistor serves as an invertor. Total phase-shift between the input fed to the first stage and the output taken from the second stage, is of 360°.

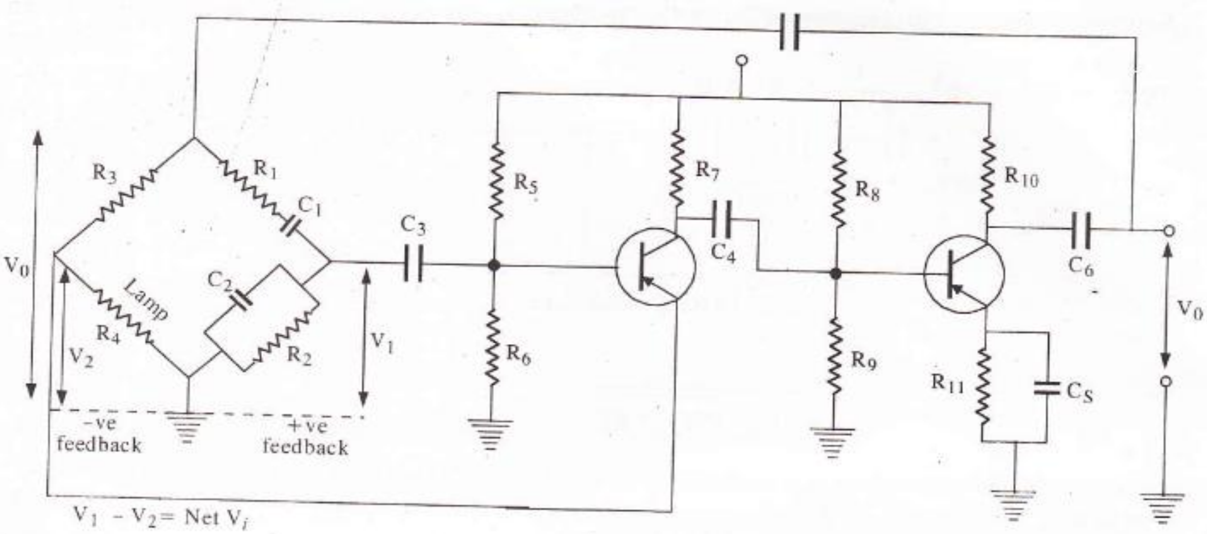


Fig. 9.11. Wien bridge oscillator

The bridge circuit has four arms; R_1 C_1, R_3, R_2 C_2 and tungston lamp L_p (R_4). Resistances R_3 and R_4 are used to stabilise the amplitude of output. The circuit uses positive and negative feedbacks. The positive feedback is through R_1C_1 and R_2C_2 to the first stage CE transistor and negative feedback is through the voltage divider to the second inverting stage CE input. The two arms of lead-lag network and the two arms of the voltage divider form a bridge. The output of the bridge is the difference of the *a.c.* voltage across parallel R_2C_2 arm and the *a.c.* voltage across R_4 which acts as V_1.

The resistor R_4 is replaced by a tungsten filament lamp which serves to stabilize the amplitude of oscillations. If there is an increase in amplitude of oscillations, the resistance of the lamp, being made up of tungsten metal will increase because of more current and its temperature will rise. This increased resistance of lamp will reduce the positive feedback and hence will bring the amplitude of oscillations to previous value.

Circuit analysis. Say, $R_1 = R_2 = R$ and $C_1 = C_2 = C$

when bridge is balanced,

$$\frac{R_3}{R_4} = \frac{R + \frac{1}{j\omega C}}{\frac{R \times \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}}} = 2 + j\,\frac{R^2 - \frac{1}{\omega^2 C^2}}{\frac{R}{\omega C}} \qquad \text{...(9.54)}$$

Equating real parts, $\frac{R_3}{R_4} = 2$ or $R_3 = 2R_4$ ...(9.55)

Equating imaginary parts, $R^2 = \frac{1}{\omega^2 C^2}$ ...(9.56)

Frequency of oscillations is, $f = \frac{1}{2\pi RC}$ Here $V_2 = \frac{R_3}{R_3 + R_4} V_0$ ...(9.57)

when bridge is balanced, then $V_2 = V_1$ refer Fig. 9.11

i.e., $\frac{R_4}{R_3 + R_4} \cdot V_0 = \frac{1}{3} V_0$ ...(after using Eq. 9.55) or At balance point $\frac{R_4}{R_3 + R_4} = \frac{1}{3}$

But for sustained oscillation, $V_i = V_1 - V_2 \neq 0$ *i.e.*, V_1 should not be equal to V_2

Indicating that the ratio $\frac{R_4}{R_3 + R_4}$ should be less than $\frac{1}{3}$.

i.e., $$\frac{R_4}{R_3 + R_4} = \frac{1}{3} - \frac{1}{n}$$

where n is a number greater than 3, now the bridge is unbalanced and $V_i \neq 0$

When bridge is unbalanced,

$$\frac{V_1}{V_0} = \frac{1}{3} \text{ done by adjusting the ratio } \frac{R_3}{R_4}. \qquad \because V_1 = \frac{V_0}{3} \text{ from 9.53}$$

but $$\frac{V_2}{V_0} = \frac{1}{3} - \frac{1}{n} \qquad \because V_2 = \frac{R_4}{R_3 + R_4} V_0 = V_0\left(\frac{1}{3} - \frac{1}{n}\right) \qquad \text{...(9.58)}$$

The feedback voltage is, $V_i = V_1 - V_2 = \left[\frac{1}{3} - \frac{1}{3} + \frac{1}{n}\right] V_0$

or $$V_i = \frac{V_0}{n} \qquad \text{...(9.59)}$$

Eq. 9.59 shows that V_i and V_0 are in phase and feedback fraction is,

$$\beta = \frac{V_i}{V_0} = \frac{1}{n} \qquad \text{...(9.60}$$

The condition $A\beta = 1$ is satisfied by making gain of the amplifier.

$$A = n \text{ where } n > 3$$

When $A\beta > 1$, oscillations are set up in the oscillator. The tungston lamp heats up thereby increasing its own resistance through increasing current. The increasing negative feedback makes the output to return to its original value. The bridge components are adjusted to make $A\beta = 1$, for sustained oscillations.

Advantages of Wien bridge oscillator

(*i*) Since it is a two stage amplifier, the overall gain is very high.

(*ii*) The sine-wave produced is of good shape.

(*iii*) Frequency stability is good.

Disadvantages

(*i*) A large number of components are required for a two stage amplifier.

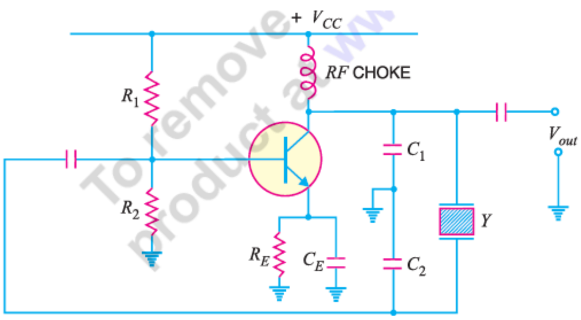
(*ii*) It cannot be used to generate very high frequencies.

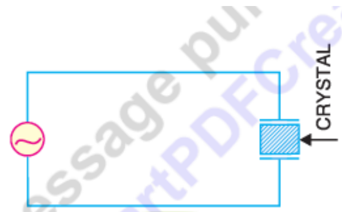
Crystal Oscillator: (Piezoelectric crystal)

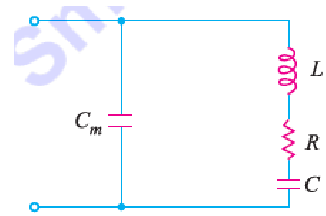
Principle: If a voltage is applied across one faces of a crystal then a mechanical stress is produced along the other faces of the crystal. This effect is called piezoelectric crystal. Thus when a piezoelectric crystal is subjected to proper alternating voltage it vibrates mechanically. The amplitude of mechanical oscillation becomes maximum when frequency of applied voltage is equal to natural frequency of the crystal.

Expression for resonant frequency:

The equivalent circuit diagram of the crystal oscillators is shown in figure 1(a).







The crystal is mounted horizontally between two metal plates as shown in figure. Using piezoelectric effect the crystal can be set into mechanical vibration with frequency depending on crystal vibration. So far as the electric properties are concerned a vibrating quartz crystal shown below in figure 1 (b) can be replaced by a equivalent LCR circuit shown in figure 1 (c), where L, C & R represent values similar to the mechanical properties of the crystal the mass, elasticity L, the L the damping respectively. C' represents the electrostatic capacitance between the electrodes with the crystals dielectrics.

The circuit has two resonant frequencies:

(i) The lower series frequency f_s which occurs when $X_L = X_{C'}$.

In that case $Z = \sqrt{R^2 + (X_L - X_C)^2} = R$ is minimum.

And $\omega L = \frac{1}{\omega C} \Rightarrow \omega^2 = \frac{1}{LC} \Rightarrow \omega = \frac{1}{\sqrt{LC}} \Rightarrow f_s = \frac{1}{2\pi\sqrt{LC}}$

It is called the series resonant frequency. At f_s the crystal acts as a series resonant circuit.

(ii) The other parallel resonant condition f_p occurs when the reactance of the series LCR is equals the reactance of capacitor C'. For which the series are becomes inductive and this inductive reactance becomes equal to the capacitive reactance of C'. i.e.

$$\omega_p L - \frac{1}{\omega_p C} = \frac{1}{\omega_p C'}$$

$$\Rightarrow \omega_p L = \frac{1}{\omega_p C} + \frac{1}{\omega_p C'}$$

$$\Rightarrow \omega_p{}^2 L = \frac{1}{C} + \frac{1}{C'}$$

$$\Rightarrow \omega_p{}^2 L = \left(\frac{C + C'}{CC'}\right)$$

$$f_p = \frac{1}{2\pi\sqrt{L\left(\frac{CC'}{C + C'}\right)}}$$

It is called the parallel resonant frequency. At f_p, the crystal act as a parallel resonant circuits. Usually, $C' >> C$, therefore $f_p = \frac{1}{2\pi\sqrt{LC}} = f_s$

Thus the series resonant frequency and parallel resonant frequencies are equal.