6.1 INTRODUCTION

Many electronic devices require a source of energy at a specific frequency, which may range from a few Hz to several MHz. This can be achieved by an electronic device called an *oscillator*. An oscillator is an electronic device which generates an alternating voltage. This may also be defined as "a circuit which generates an A.C output signal without requiring any externally applied input signal". The oscillator converts D.C energy into A.C energy at a very high frequency. So the function of an oscillator is opposite to that of a rectifier which converts A.C power into D.C power.

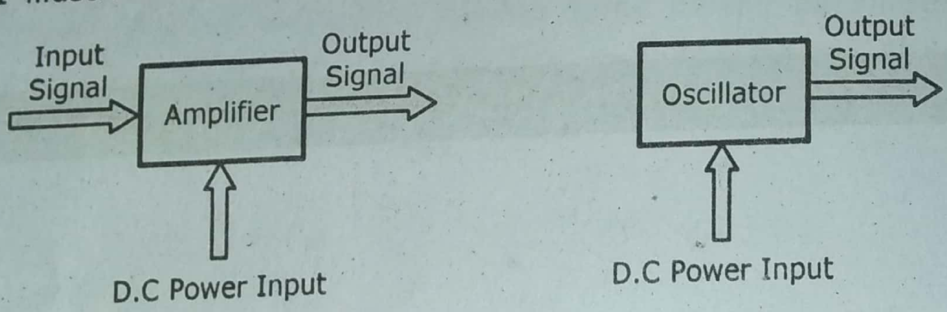
The function of an oscillator circuit is similar to that of an amplifier circuit. However, an oscillator differs from an amplifier in one respect, that can be stated as follows,

(1) An amplifier produces an output signal whose waveform is similar to the input signal but whose power level is generally high. This additional power is supplied by the external D.C source. Hence, an amplifier is essentially an energy converter i.e., it takes energy from the D.C power source and converts it into A.C energy at signal frequency.

(2) On the other hand, an oscillator does not require an input source to start or maintain energy conversion process. It keeps producing an output signal so long as the D.C power source is connected.

Thus an oscillator can be regarded as an amplifier which provides its own input signal.

Fig. 6.1.1 illustrates the comparison of oscillator and an amplifier,



(a) Amplifier (b) Oscillator

Fig. 6.1.1 Illustrating Comparison of Amplifier and Oscillator

Positive Feedback : The use of positive feedback is extremely useful in producing oscillations. The condition for positive feedback is that a portion of output is combined in phase with the input. For an amplifier with positive feedback, the gain is given by following expression,

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

If $A\beta = 1$ then $A_f = \infty$. This is only possible when input signal is zero. Thus the amplifier is capable of producing output even when input is zero. Under this condition, an amplifier works as an oscillator.

6.1.1 Classification of Oscillators

Oscillators are classified into the following different ways,

(1) According to the Nature of Waveforms Generated

(i) Sinusoidal (or) Harmonic Oscillators : An electronic device that generate sinusoidal oscillations of desired frequency is known as a sinusoidal oscillator. A transistor oscillator is a sinusoidal oscillator.

Fig. 6.1.2 shows sinusoidal waveform,

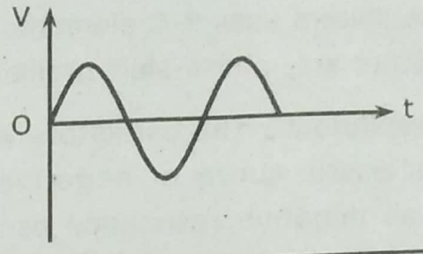


Fig. 6.1.2 Sinusoidal Waveform

(ii) Non-sinusoidal (or) Relaxation Oscillators : The oscillators, which produce square waves, triangular waves, pulses or saw tooth waves are known as relaxation or non-sinusoidal oscillators. Multivibrators, sweep generators, blocking oscillators etc., are examples of non-sinusoidal oscillators.

Fig. 6.1.3 shows non-sinusoidal waveforms,

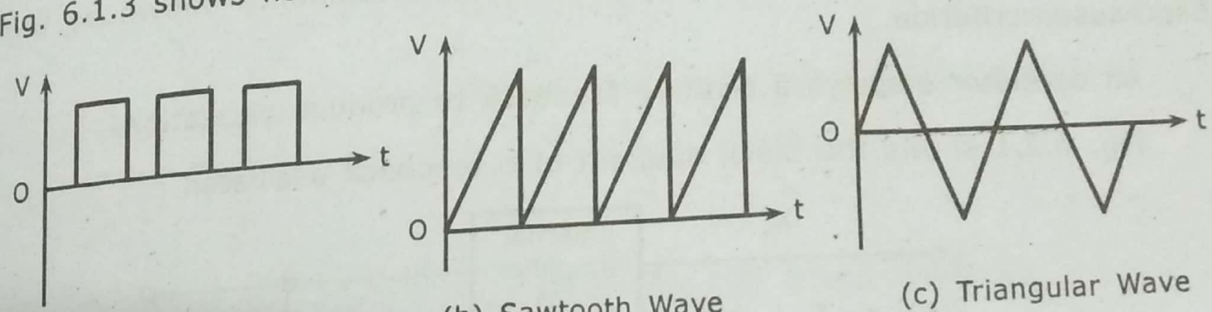


Fig. 6.1.3 Non Sinusoidal Waveforms

(2) According to the Fundamental Mechanisms Involved

(i) Negative Resistance Oscillators : Negative resistance oscillator uses negative resistance of the amplifying device to neutralize the positive resistance of the oscillator.

(ii) Feedback Oscillators : Feedback oscillator uses positive feedback in the feedback amplifier to satisfy the Barkhausen Criterion.

(3) According to the Frequency of the Generated Signals

(i) Audio Frequency Oscillator (AFO) : Upto 20KHz.

(ii) Radio Frequency Oscillator (RFO) : 20KHz to 30MHz.

(iii) **Very High Frequency Oscillators :** 20MHz to 300MHz.

(iv) **Ultra High Frequency Oscillators :** 300MHz to 3GHz.

(v) **Microwave Frequency Oscillators :** 3GHz to several GHz.

(4) **According to the Type of Circuit Used :** On the basis of circuit used, oscillators can be classified as,

(i) **LC Oscillators :** LC oscillators uses LC elements as feedback network. Example of these type of oscillators are Hartley oscillator, Colpitts oscillator and Clap oscillator.

(ii) **R-C Oscillators :** R-C oscillators uses R-C elements as feedback network. Example of these type of oscillators are, phase-shift oscillators and Weinbridge oscillators.

(iii) **Negative Resistance Oscillators :** The oscillators which use an active device that possess a V-I characteristic curve of negative slope within some range of operation are known as negative resistance oscillators. Tuned diode oscillator is an example of negative resistance oscillators.

6.2 BARKHAUSEN CRITERION

An oscillator circuit is essentially an amplifier circuit with a frequency-selective positive feedback network. The feedback network feeds a portion of the amplifier output to its input in such a way to satisfy the two fundamental requirements for occurrence of sustained oscillations. These requirements are commonly known by the name of Barkhausen criterion.

An oscillator employs a positive feedback to produce oscillations.

Fig. 6.2.1 shows the block diagram of a feedback oscillator.

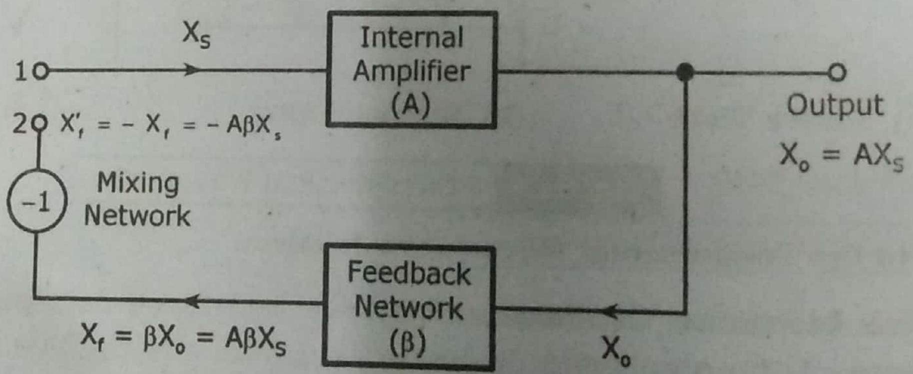


Fig. 6.2.1 Block Diagram of Feedback Oscillator

It consists of an internal amplifier of gain A, a feedback network β and mixing network.

Let the input signal be X_S resulting in an output signal X_o. The feedback network samples of this output signal X_o resulting in feedback voltage X_f at the output of the feedback network.

Then, $X_f = \beta X_o = A\beta X_S$

The mixing network inverts the feedback voltage X_f, thus,

$$X'_f = -X_f = -A\beta X_S$$

Let it be so arranged that X'_f is identical with X_S. If now the external source X_S is removed and terminal 2 is connected to terminal 1, the amplifier continues to provide at its output the same voltage X_o as before without needing any external input signal. Obviously the system now functions as an oscillator.

The necessary condition for oscillation is,

$$\boxed{X'_f = X_S} \quad \text{... (6.2.1)}$$

Eq. (6.2.1) signifies that for sustained oscillations, instantaneous values of X'_f and X_S are identical at all times. No restriction is imposed regarding the waveform of signal, it may be sinusoidal or may have any other shape.

From Fig. (6.2.1), $X'_f = -A\beta X_S$. Hence Eq. (6.2.1) for sustained oscillation may be written as,

$$-A\beta X_S = X_S$$

$$\Rightarrow \quad -A\beta = 1$$

$$\therefore \quad \boxed{A\beta = -1} \quad \text{... (6.2.2)}$$

Quantity $-A\beta$ is the loop gain of the complete feedback amplifier circuit.

Eq. (6.2.2) can be expressed in the rectangular form as,

$$A\beta = -1 + j0$$

Thus we get the two conditions for magnitude and phase angle as,

Magnitude Condition : $|A\beta| = \sqrt{1^2 + 0^2} = 1$

Phase Condition : $\angle A\beta = \tan^{-1}\left(\frac{0}{1}\right) = 0° \text{ or } = 2\pi n$ radians

Where, n = 0, 1, 2, ... and so on.

These conditions are necessary and sufficient for the circuit to behave as an oscillator. These conditions are called as Barkhausen criterion.

6.2.1 Barkhausen Criterion Conditions

(1) **Magnitude Condition :** The magnitude or gain around a closed loop must be equal to 1 (unity).

$$|A\beta| = 1$$

(2) **Phase Angle Condition :** The total phase shift around the feedback loop must be equal to 0° or $2\pi n$ radians.

$$\angle A\beta = 0^\circ \text{ (or)}$$
$$= 2\pi n \text{ radians} \qquad \text{(where } n = 0, 1, 2 \ldots \text{ and so on).}$$

6.2.2 Effect of the Value |Aβ| on the Nature of Oscillations

Three different kinds of oscillations produced for the various values of $|A\beta|$ and are explained as follows,

6.2.2.1 |Aβ| = 1 (Undamped Oscillations)

When the total phase shift around a loop is 0° and $|A\beta| = 1$, then the output oscillates with constant frequency and amplitude. These are called as sustained oscillations and are shown in Fig. 6.2.2,

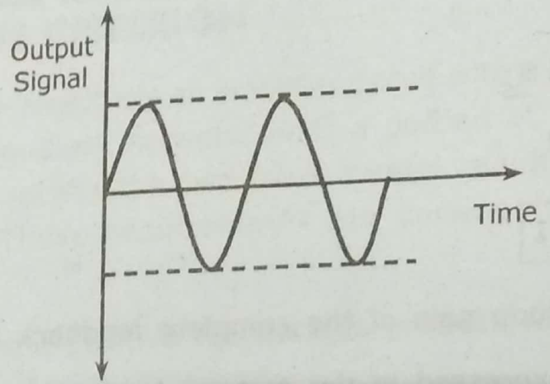


Fig. 6.2.2 Undamped Oscillations, $|A\beta| = 1$

6.2.2.2 |Aβ| < 1 (Damped Exponential Decay Oscillations)

When the total phase shift around a loop is 0° and $|A\beta| < 1$, then the output oscillations are of exponentially decaying and finally ceases, this type of oscillations are shown in Fig. 6.2.3,

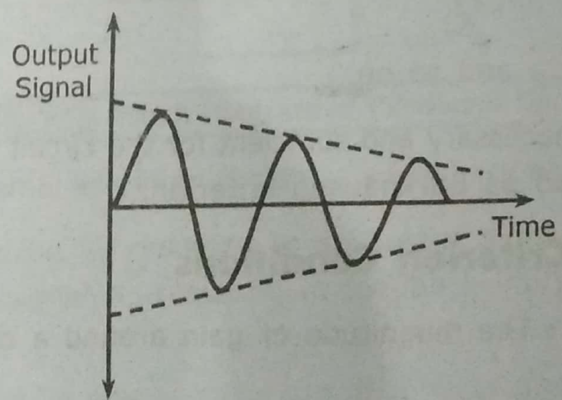


Fig. 6.2.3 Damped Exponential Decay Oscillations

6.2.2.3 |Aβ| > 1 (Damped Exponential Rise Oscillations)

When the total phase shift around a loop is 0° (or $2\pi n$) and $|A\beta| > 1$, then the output oscillations are of growing type as shown in Fig. 6.2.4,

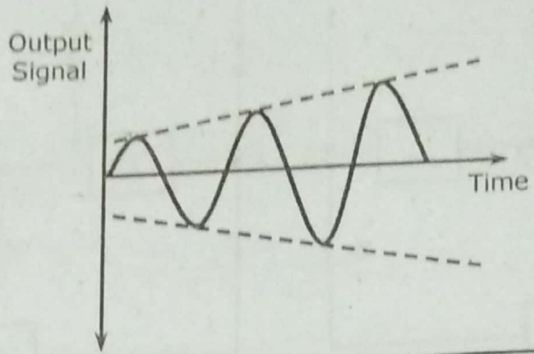


Fig. 6.2.4 Damped Exponential Rise Oscillations ($|A\beta| > 1$)

For practical oscillators, $|A\beta|$ is kept slightly higher than one to compensate for the non linearities existing in the circuit. But for theoretical analysis, we are going to neglect the effect of non linearities.

HOW DOES STARTING VOLTAGE COMES FROM?

It is seen that in case of oscillators, external input is not required. The oscillator output feeds its own input. The question is, where does the starting voltage comes from?

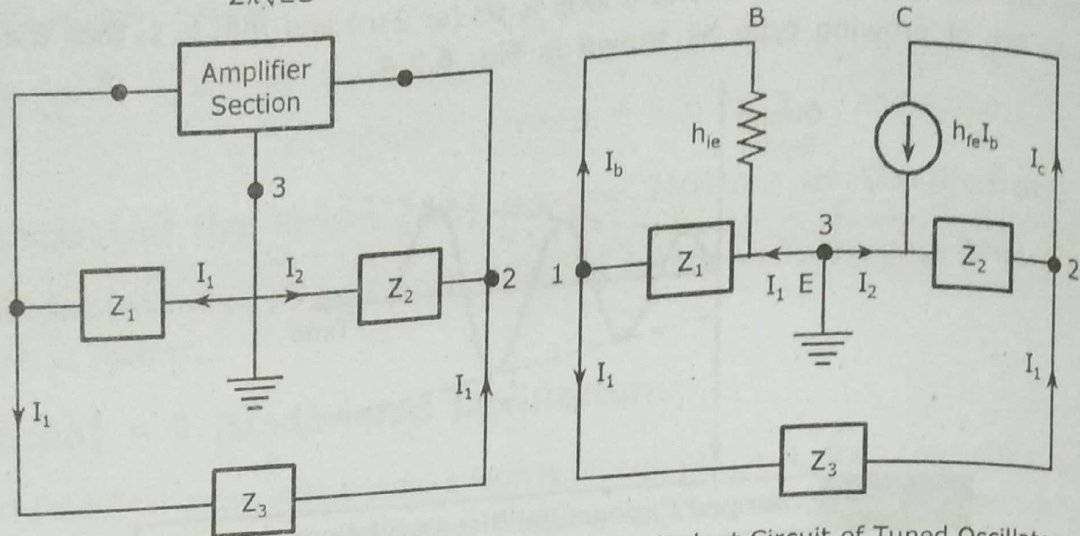
Every resistance has some free electrons. Under the influence of normal room temperature, these free electrons move randomly in various directions. Such a movement of the free electrons generate a voltage across the resistance, this is going to be amplified and appears at the output terminals. This output is sufficient to drive the feedback circuit, which provides sufficient input to drive the amplifier circuit.

6.3 LC TYPE OSCILLATORS

Unlike the RC oscillators, the LC oscillators employs the elements L and C in their feedback network. Tuned LC oscillators are good for generating high frequency oscillations. At low frequencies, the inductor and capacitors would be bulky and so are not suitable. Thus RC oscillators are used at low frequencies. Before studying the LC oscillators such as Hartley, and Colpitts oscillators, let us develop a generalized expression for LC (tuned) oscillator.

Generalized form of tuned oscillators is shown in Fig. 6.3.1(a), any of the active devices such as vacuum tube, transistor, FET and operational amplifier may be used in amplifier section. Z_1, Z_2 and Z_3 are reactive elements constituting the feedback tank circuit which determines the frequency of oscillation. Here, Z_1 and Z_2 serves as an A.C voltage divider for the output voltage and feedback signal. Therefore, the voltage across Z_3 is the feedback signal. The frequency of oscillation of LC oscillator is,

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



(a) General Tuned Oscillators

(b) Equivalent Circuit of Tuned Oscillator

Fig. 6.3.1 General Form and its Equivalent Circuit

The inductive or capacitive reactances are represented by Z_1, Z_2 and Z_3. In Fig. 6.3.1, the output terminals are 2 and 3 and input terminals are 1 and 3. Fig. 6.3.1(b) gives the equivalent circuit of Fig. 6.3.1(a). Here, two assumptions have been made to draw the equivalent circuit shown in Fig. 6.3.1(b).

(1) h_{re} of transistor is negligibly small and hence the feedback source $h_{re}V_o$ is neglected from the equivalent circuit.

(2) h_{oe} of transistor is very small i.e., $1/h_{oe}$ output resistance is very large. Hence $1/h_{oe}$ is eliminated from the equivalent circuit.

(1) Load Impedance : Since, Z_1 and the input resistance h_{ie} of the transistor are in parallel, their equivalent impedance Z' is given by,

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

$$\therefore \quad Z' = \frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \qquad \text{... (6.3.1)}$$

Now the load impedance Z_L between the output terminals 2 and 3 is the equivalent impedance of Z_2 in parallel with the series combination of Z' and Z_3 given by,

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

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

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

$$\therefore \quad Z_L = \frac{Z_2 \left[h_{ie}(Z_1 + Z_3) + Z_1 Z_3\right]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \qquad \text{... (6.3.2)}$$

(2) **Voltage Gain Without Feedback** : Voltage gain of oscillator without feedback is given as,

$$A_v = -\frac{h_{fe} Z_L}{h_{ie}} \qquad \text{... (6.3.3)}$$

(3) **Feedback Fraction β :** The output voltage between the terminals 3 and 2 in terms of the current I_1 is given by,

$$V_0 = -I_1(Z' + Z_3) = -I_1\left(\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3\right) \qquad \left(\because Z' = \frac{Z_1 h_{ie}}{Z_1 + h_{ie}}\right)$$

$$= -I_1\left(\frac{h_{ie}(Z_1 + Z_3) + Z_1 Z_3}{Z_1 + h_{ie}}\right) \qquad \text{... (6.3.4)}$$

The voltage feedback to the input terminals 3 and 1 is given by,

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

$$= -I_1\left(\frac{X_1 h_{ie}}{X_1 + h_{ie}}\right) \qquad \text{... (6.3.5)}$$

Therefore, the feedback ratio β is given by,

$$\beta = \frac{V_{fb}}{V_o} = \frac{-I_1\left[\frac{Z_1 h_{ie}}{Z_1 + h_{ie}}\right]}{-I_1\left[\frac{h_{ie}(Z_1 + Z_3) + Z_1 Z_3}{Z_1 + h_{ie}}\right]}$$

$$= \frac{Z_1 h_{ie}}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3} \qquad \text{... (6.3.6)}$$

(4) **Generalized Equation for the Oscillator :** For sustained oscillations, we must have loop gain equal to unity i.e.,

$$A_v\beta = 1$$

Substituting the values of A_v and β, we get,

$$\left(\frac{-h_{fe}Z_L}{h_{ie}}\right)\left[\frac{Z_1 h_{ie}}{h_{ie}(Z_1+Z_3)+Z_1Z_3}\right] = 1$$

$$\left[\frac{h_{fe}Z_2\left[h_{ie}(Z_1+Z_3)+Z_1Z_3\right]}{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3}\right]\left[\frac{Z_1}{h_{ie}(Z_1+Z_3)+Z_1Z_3}\right] = -1$$

$$\frac{h_{fe}Z_2Z_1}{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3} = -1$$

$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3 = -h_{fe}Z_1Z_2$$

$$\therefore \quad \boxed{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3 = 0} \quad \text{... (6.3.7)}$$

Eq. (6.3.7) represents the generalized equation for the tuned oscillator. Two types of tuned oscillator circuits can be built when the reactive components (Z_1, Z_2 and Z_3) shown in the Fig. 6.3.1 are L and C.

Table 6.3.1 gives the type of the oscillator circuits obtained when the different reactive elements are designated.

Table 6.3.1 Tuned Oscillator Circuits by Changing the Reactive Components

Oscillator	Reactive Components		
	Z_1	Z_2	Z_3
Hartley Oscillator	C	C	L
Colpitts Oscillator	L	L	C

6.3.1 Hartley Oscillator

If Z_1, Z_2 are choosen to be inductive and Z_3 capacitive, the oscillator is called as Hartley oscillator. The circuit arrangement of Hartley oscillator is shown in Fig. 6.3.2,

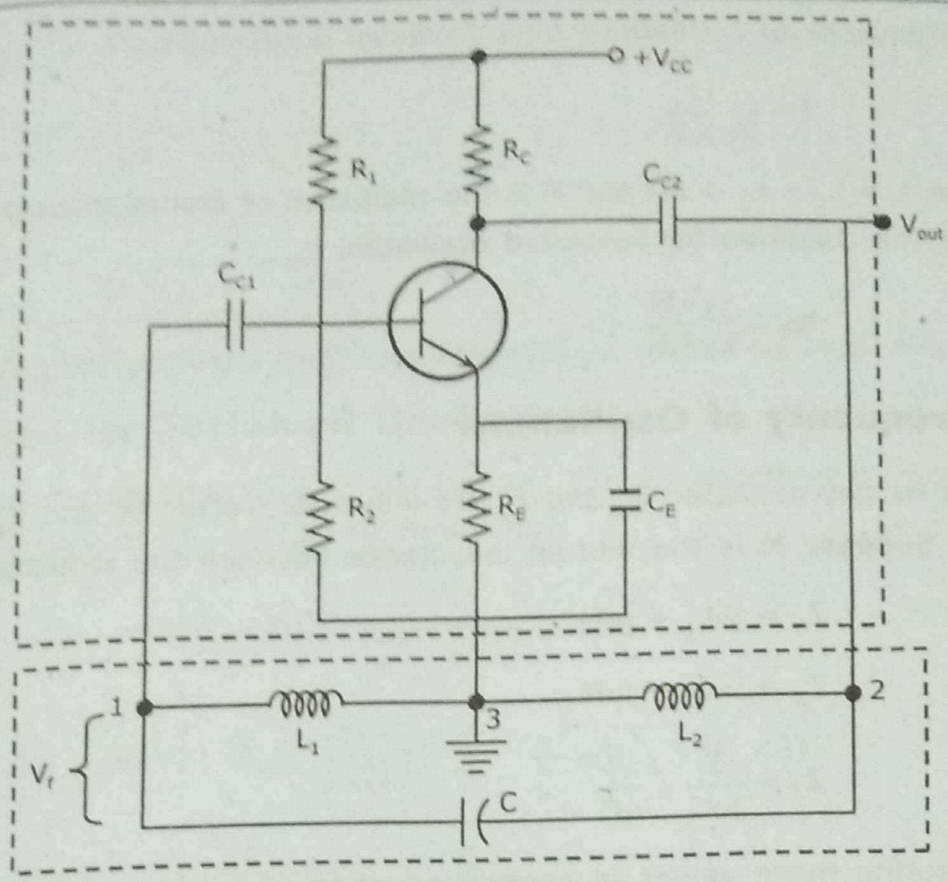


Fig. 6.3.2 Hartley Oscillator

CONSTRUCTION

Resistors R_1, R_2 and R_E provides the necessary D.C bias to the transistor. C_E is a bypass capacitor. C_{C1} and C_{C2} are coupling capacitors. The feedback network consisting of inductors L_1, L_2 and capacitor C determines the frequency of the oscillator.

WORKING OPERATION

When the supply voltage $+V_{CC}$ is turned ON, a transient current is produced in the tank circuit and consequently, damped harmonic oscillations are set up in the circuit. The oscillatory current in the tank circuit produces A.C voltages across L_1 and L_2. Since, terminal 3 is grounded, it has a zero potential. If terminal 1 is at a positive potential with respect to 3 at any instant, terminal 2 will be a negative potential with respect to 3 at the same instant. Thus the phase difference between terminals 1 and 2 is always 180°. In the CE mode, the transistor provides the phase difference of 180° between the input and output. Therefore the total phase shift is 360°. This makes the feedback positive which is the essential condition for oscillations. When the loop gain $|A\beta|$ of the amplifier is made equal to one using the suitable components in the feedback network the circuit acts as an oscillator.

The frequency of oscillations thus produced is given by,

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

Where, $L = L_1 + L_2 + 2M$ and M is the coefficient of mutual inductance between coils L_1 and L_2. The condition for sustained oscillation is,

$$h_{fe} \geq \frac{L_1 + M}{L_2 + M}$$

6.3.1.1 Frequency of Oscillations

In the Hartley oscillator, Z_1 and Z_2 are inductive reactances and Z_3 is the capacitive reactance. Suppose M is the mutual inductance between the inductors,

Then,
$$Z_1 = j\omega L_1 + j\omega M$$
$$Z_2 = j\omega L_2 + j\omega M$$
$$Z_3 = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

Substituting these values in general equation of tuned oscillator, i.e.,

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1Z_2(1 + h_{fe}) + Z_1Z_3 = 0$$

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

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

$$\Rightarrow \quad j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] - \omega^2(L_1 + M)\left[(L_2 + M)(1 + h_{fe}) - \frac{1}{\omega^2 C}\right] = 0 \quad \ldots (6.3.8)$$

Equating the imaginary part equal to zero, we get,

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

$$\Rightarrow \quad L_1 + L_2 + 2M - \frac{1}{\omega^2 C} = 0 \qquad (\because h_{ie} \neq 0)$$

$$\Rightarrow \quad \omega^2 C = \frac{1}{L_1 + L_2 + 2M} \quad \ldots (6.3.9)$$

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

$$\Rightarrow \quad 2\pi f = \frac{1}{\sqrt{(L_1 + L_2 + 2M)C}} \qquad (\because \ \omega = 2\pi f)$$

$$\therefore \quad \boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}}} \qquad \text{... (6.3.10)}$$

Hence, Eq. (6.3.10) gives the frequency of sustained oscillation, in Hartley oscillator.

6.3.1.2 Condition for Sustained Oscillations

The condition for maintenance of oscillations can be obtained by equating the coefficients of real part of Eq. (6.3.8) to zero. Thus,

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

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

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

$$\Rightarrow \quad (1 + h_{fe}) = \frac{(L_1 + L_2 + 2M)}{(L_2 + M)} \qquad \left(\because \omega^2 C = \frac{1}{L_1 + L_2 + 2M} \text{ using Eq. (6.3.9)}\right)$$

$$= \frac{(L_1 + M) + (L_2 + M)}{(L_2 + M)} = 1 + \left[\frac{L_1 + M}{L_2 + M}\right]$$

$$\therefore \quad \boxed{h_{fe} = \left[\frac{L_1 + M}{L_2 + M}\right]} \qquad \text{... (6.3.11)}$$

Eq. (6.3.11) gives the condition for the maintenance of sustained oscillations in Hartley oscillator.

6.3.1.3 Advantages of Hartley Oscillator

The advantages of Hartley oscillator are the following,

(1) Frequency can be adjusted by variable capacitor C.

(2) Instead of two separate coils L_1, L_2, a single coil of bare wire can be used and coil grounded at any desired point along it.

(3) The output amplitude remains constant over the frequency range.

EXAMPLE PROBLEM 1

Calculate the Operating frequency and Feedback fraction for Hartley oscillator shown in Fig. 6.3.3 for which the mutual inductance between the coils is M = 20 μH.

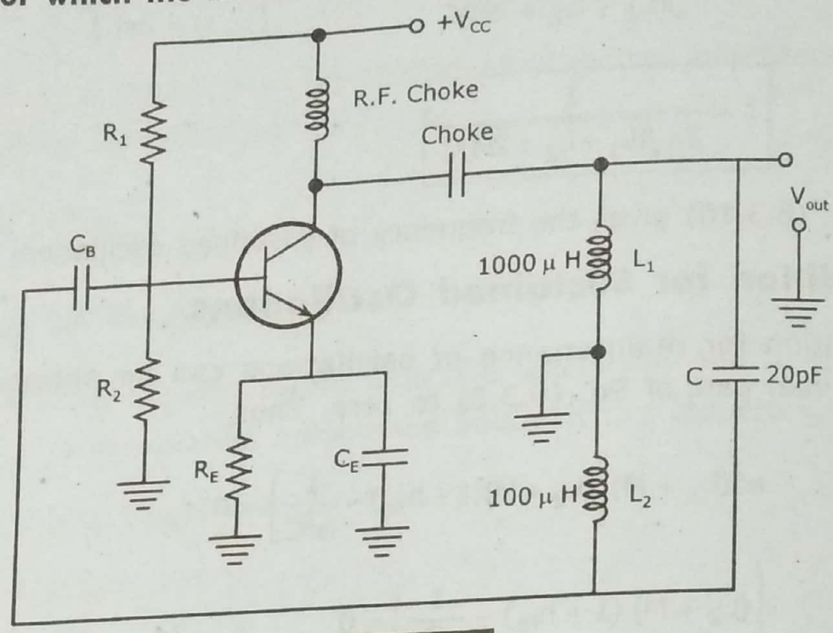


Fig. 6.3.3

SOLUTION

Given data : $L_1 = 1000\ \mu H$, $L_2 = 100\ \mu H$

$M = 20\ \mu H$, $C = 20\ pF = 20 \times 10^{-12}\ F$

(i) We know that operating frequency of Hartley oscillator is,

$$f = \frac{1}{2\pi\sqrt{L_T C}} \quad \text{... (6.3.12)}$$

Where,

$L_T = L_1 + L_2 + 2M \rightarrow$ Total inductance

$\therefore \quad L_T = 1000\ mH + 100\ mH + 2 \times 20\ mH$

$= 1140\ mH$

Substituting the value in Eq. (6.3.5), we have

$$f = \frac{1}{2\pi\sqrt{1140 \times 10^{-6} \times 20 \times 10^{-12}}} = 1.05\ MHz$$

(ii) Feedback fraction (β) in Hartely oscillator given as,

$$\beta = \frac{L_2}{L_1} = \frac{100\mu H}{1000\mu H} = 0.1.$$

6.3.2 Colpitts Oscillator

If Z_1 and Z_2 are choosen to be capacitive and Z_2 be inductive, then oscillator configuration is called Colpitts oscillator.

Circuit arrangement of Colpitt's oscillator circuit is shown in Fig. 6.3.4,

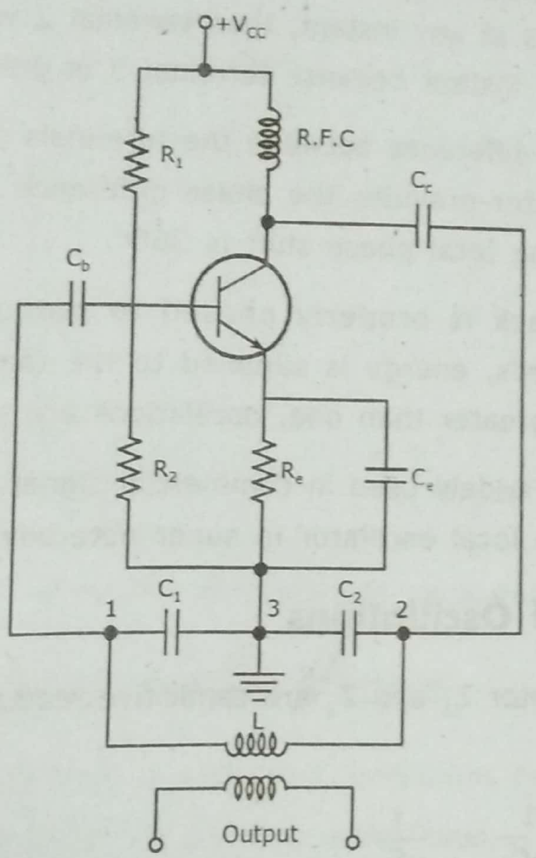


Fig. 6.3.4 Colpitt's Oscillator

CONSTRUCTION

The resistors R_1, R_2 and R_e provide the necessary bias conditions for the circuit. The parallel combination of R_e and C_e in the emitter circuit is the stabilizing circuit. The function of C_c and C_b is to block D.C and to provide an A.C path. The Radio Frequency Choke (R.F.C) offers very high impedance to high frequency currents. Thus it prevents radio frequency currents from reaching the source of collector supply voltage and prevents this source from short-circuiting the alternating output voltage. The frequency determining network is a parallel resonant circuit consisting of capacitors C_1 and C_2 and the inductor L. The junction of C_1 and C_2 is grounded. The voltage developed across C_1 provides the regenerative feedback required for the sustained oscillations.

WORKING OPERATION

When the collector supply voltage is switched on, a transient current is produced in the tank circuit. So damped harmonic oscillations are produced in the tank circuit. The oscillations across C_1 are applied to the base emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit. If terminal 1 is at positive potential with respect to 3 at any instant, then terminal 2 will be at negative potential with respect to 3 at that instant because terminal 3 is grounded.

Therefore the phase difference between the terminals 1 and 2 is always 180°. In the CE mode, the transistor provides the phase difference of 180° between the input and output. Therefore, the total phase shift is 360°.

In this way, feedback is properly phased to produce continuous undamped oscillations. In other words, energy is supplied to the tank circuit in phase with the oscillations and if $A\beta$ is greater than one, oscillations are sustained in the circuit.

Colpitt's oscillator is widely used in commercial signal generators of about 1 MHz. It can also be used as a local oscillator in super heterodyne radio receiver.

6.3.2.1 Frequency of Oscillations

In the Colpitts oscillator Z_1 and Z_2 are capacitive reactances and Z_3 is the inductive reactance, then

$$Z_1 = \frac{1}{j\omega C_1} = -\frac{j}{\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2} = -\frac{j}{\omega C_2}$$

$$Z_3 = j\omega L$$

Substituting these values in generalized equation of tuned oscillator, that is,

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1Z_2(1 + h_{fe}) + Z_1Z_3 = 0$$

$$\Rightarrow \quad h_{ie}\left[-\frac{j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L\right] + \left[-\frac{j}{\omega C_1}\right]\left[-\frac{j}{\omega C_2}\right](1 + h_{fe}) + \left[-\frac{j}{\omega C_1}\right] j\omega L = 0$$

$$\Rightarrow \quad -jh_{ie}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right] - \frac{1 + h_{fe}}{\omega^2 C_1C_2} + \frac{L}{C_1} = 0$$

$$\Rightarrow \quad jh_{ie}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right] + \left[\frac{1 + h_{fe}}{\omega^2 C_1C_2} - \frac{L}{C_1}\right] = 0 \quad \text{... (6.3.13)}$$

Equating the imaginary part of Eq. (6.3.13) equal to zero, we have,

$$h_{ie}\left[\frac{1}{\omega C_1}+\frac{1}{\omega C_2}-\omega L\right]=0$$

$$\Rightarrow \quad \frac{1}{\omega C_1}+\frac{1}{\omega C_2}=\omega L \qquad (\because h_{ie}\neq 0)$$

$$\Rightarrow \quad \frac{C_2+C_1}{\omega C_1C_2}=\omega L$$

$$\Rightarrow \quad \omega^2=\frac{C_1+C_2}{L(C_1C_2)}$$

$$\Rightarrow \quad \omega=\sqrt{\frac{C_1+C_2}{LC_1C_2}}$$

$$\Rightarrow \quad \boxed{f=\frac{1}{2\pi}\sqrt{\left\{\frac{(C_2+C_1)}{LC_1C_2}\right\}}} \qquad (\because \omega=2\pi f) \qquad ....(6.3.14)$$

$\therefore$

Therefore, Eq. (6.3.14) gives the frequency of oscillations in Colpitts oscillator.

6.3.2.2 Condition for Sustained Oscillations

The condition for maintenance of sustained oscillations can be obtained by equating the coefficients of real part of Eq. (6.3.13) to zero. Thus,

$$\frac{1+h_{fe}}{\omega^2C_1C_2}=\frac{L}{C_1}$$

$$\Rightarrow \quad 1+h_{fe}=\frac{\omega^2LC_1C_2}{C_1}=\omega^2LC_2$$

$$=\frac{(C_1+C_2)}{L(C_1C_2)}(LC_2) \qquad \left(\because \omega=\sqrt{\frac{C_1+C_2}{L(C_1C_2)}}\right)$$

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

$$\therefore \quad \boxed{h_{fe}=\left(\frac{C_2}{C_1}\right)} \qquad ...\ (6.3.15)$$

Eq. (6.3.15), gives the condition for maintenance of sustained oscillations in Colpitts oscillator.

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EXAMPLE PROBLEM 1

In the Colpitts oscillator C_1 = 0.2 μF and C_2 = 0.02 μF. If the frequency of the oscillator is 10 kHz, find the value of the inductor. Also find the required gain for oscillation.

SOLUTION

Given Data : C_1 = 0.2 μF and C_2 = 0.02 μF

f_0 = 10 KHz

The frequency of the Colpitts oscillator is given by,

$$f_o = \frac{1}{2\pi}\sqrt{\frac{C_1 + C_2}{LC_1C_2}}$$

$$\Rightarrow \quad L = \frac{C_1 + C_2}{4\pi^2 f_0^2 C_1 C_2} = \frac{0.22 \times 10^{-6}}{4\pi^2 \times (10 \times 10^3)^2 \times 0.2 \times 10^{-6} \times 0.02 \times 10^{-6}}$$

$$\therefore \quad L = 13.932 \text{ mH.}$$

The current gain required to produce oscillations is,

$$h_{fe} = \frac{C_2}{C_1} = \frac{0.02 \times 10^{-6}}{0.2 \times 10^{-6}}$$

$$= 0.1$$

6.4 RC TYPE OSCILLATORS

For low frequency applications (i.e., audio frequencies) oscillators using passive elements R and C are extensively used. There are two types of RC oscillators and they are,

(1) RC phase shift oscillator.

(2) Wein-bridge oscillator.

Principle of RC Oscillators : The basic RC phase shift oscillator comprises a single-stage amplifier whose output is fed back to its input through a feedback network. The amplifier portion is usually implemented by either a bipolar junction transistor-based common-emitter amplifier stage or an operational amplifier wired as an inverting amplifier. The feedback network comprises a cascade arrangement for three identical sections of either lag or lead type RC network.

Fig. 6.4.1 shows the block schematic of an RC oscillator.

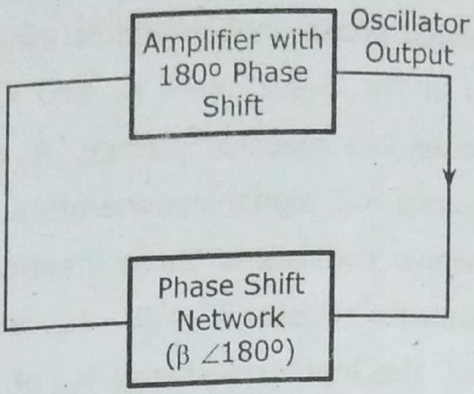

Fig. 6.4.1 Schematic Block of RC Oscillators

The basic amplifier in Fig. 6.4.1 provides a phase shift of 180°, and the feedback network provides another 180° phase shift, so that the total phase shift is 360° or 0° in order to have positive feedback which is essential for oscillations. It may be noted that any integral multiple of 2π or 360° is equivalent to 0° phase shift.

6.4.1 RC Phase Shift Oscillator

Fig. 6.4.2 shows the circuit diagram of an RC phase shift oscillator using CE amplifier stage and a lag type RC network,

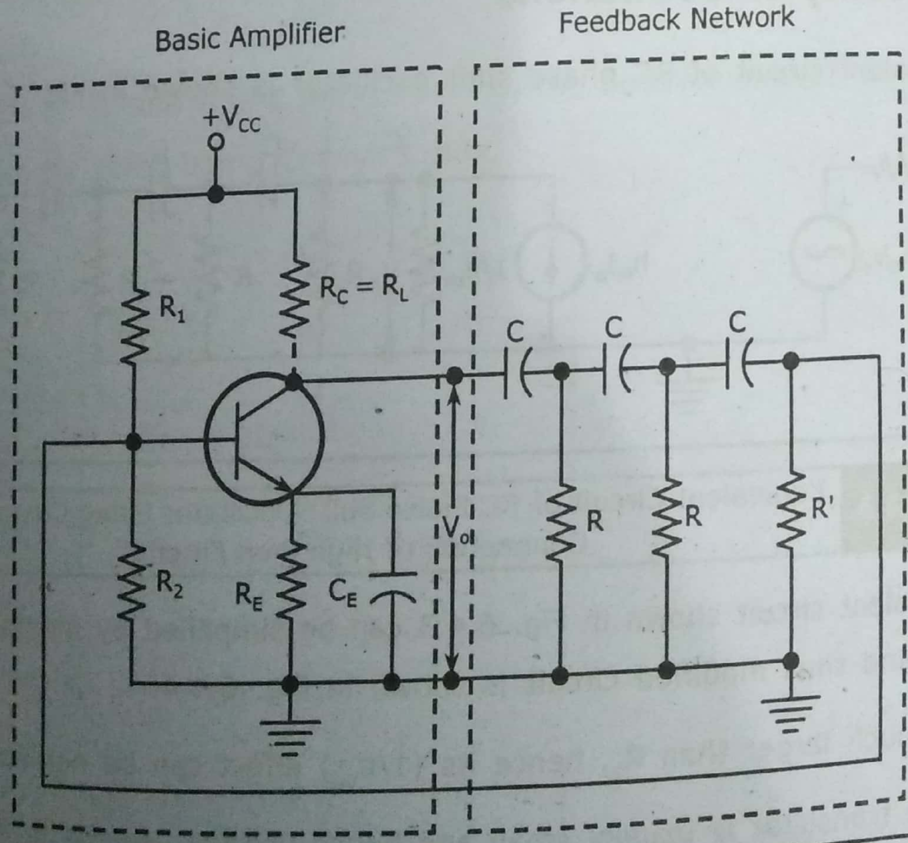

Fig. 6.4.2 Circuit Diagram of an RC Phase Shift Oscillator using BJT

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6.4.1.1 Construction

The circuit arrangement of RC phase shift oscillator using NPN transistor in common emitter configuration is shown in Fig. 6.4.2. Here R_1 and R_2 provides D.C emitter base bias. R_L is the load which controls the collector voltage. R_E and R_C combination provides temperature stability and prevents A.C signal degeneration. The output of the amplifier goes to a feedback network, which consists of three identical R-C sections. It should be noted that the last section contains a resistor $R' = R - h_{ie}$. Since this resistor is connected with the base of the transistor, the input resistance h_{ie} of the transistor is added to it gives a total resistance R.

6.4.1.2 Working Operation

R-C network produces a phase shift of 180° between input and output voltage. Since, C-E amplifier produces a phase shift of 180°, the total phase change becomes 360° or 0° which is the essential requirement of sustained oscillations. The RC phase shift networks serve as frequency determining circuit since only at a single frequency the net phase shift around the loop will be 360°, a sinusoidal waveform at this frequency is generated. These oscillators are used for audio frequency range.

6.4.1.3 Frequency of Oscillations

The equivalent circuit of RC phase shift oscillator is shown in Fig. 6.4.3,

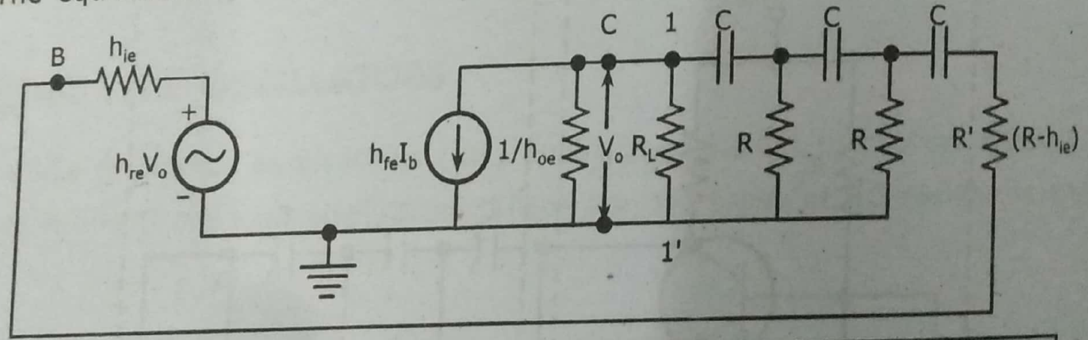

Fig. 6.4.3 Equivalent Circuit of RC Phase Shift Oscillator Using Cascading Connection of High Pass Filter

The equivalent circuit shown in Fig. 6.4.3 can be simplified by making the following assumptions, and thus modified circuit is shown in Fig. 6.4.4.

(1) $1/h_{oe}$ is much larger than R_L, hence its $(1/h_{oe})$ effect can be neglected.

(2) h_{re} of the transistor is usually small and hence voltage source $h_{re}V_o$ is eliminated from the circuit.

Replacing the circuit to the left of points 11' by its Thevenin's equivalent, we get the circuit shown in Fig. 6.4.4,

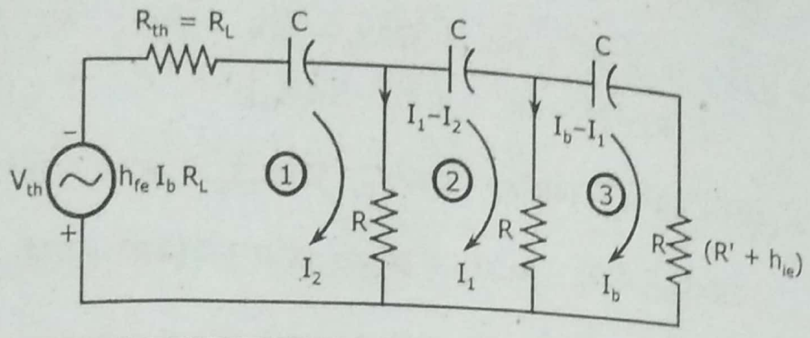

Fig. 6.4.4 Modified RC Phase Shift Oscillator Equivalent Circuit

From Fig. 6.4.4 the loop equations are given by,

Loop 3 : $\left(\frac{1}{j\omega C}+R\right)I_b+(I_b-I_1)R=0$ ... (6.4.1)

Loop 2 : $\left(\frac{1}{j\omega C}\right)I_1+(I_1-I_b)R+(I_1-I_2)R=0$ ... (6.4.2)

Loop 1 : $h_{fe}I_bR_L+\left(R_L+R+\frac{1}{j\omega C}\right)I_2-I_1R=0$ ... (6.4.3)

As current I_1, I_2 and I_b are non-vanishing, the determinants of the coefficient of I_1, I_2 and I_b must be zero. Using Cramer's rule,

We have,

$$\begin{array}{ccc} I_b & I_1 & I_2 \end{array}$$
$$\begin{vmatrix} 2R+\frac{1}{j\omega C} & -R & 0 \\ -R & 2R+\frac{1}{j\omega C} & -R \\ h_{fe}R_L & -R & R+R_L+\frac{1}{j\omega C} \end{vmatrix} = \Delta$$

Substituting $X_C = \frac{1}{\omega C}$, we get,

$$\begin{vmatrix} 2R-jX_C & -R & 0 \\ -R & 2R-jX_C & -R \\ h_{fe}R_L & -R & R+R_L-jX_C \end{vmatrix} = \Delta$$

$$\Rightarrow \quad \Delta = [(2R - jX_C)[(2R - jX_C)(R + R_L - jX_C) - R^2)] - [(-R)[(-R)(R + R_L - jX_C) - (-R)(h_{fe}R_L)] \quad \dots (6.4.4)$$

$$= [(2R - jX_C)[2R^2 + 2RR_L - j2RX_C - jRX_C - jR_LX_C - X^2_C - R^2]] - [(-R)[-R^2 - RR_L + jRX_C + RR_Lh_{fe}]]$$

$$= [4R^3 + 4R^2R_L - j4R^2X_C - j2R^2X_C - j2RR_LX_C - 2RX^2_C - 2R^3 - j2R^2X_C - 2RR_LX_C - 2RX^2_C - RX^2_C - RLX^2_C + jX^3_C + jX_CR^2] - [+R^3 + R^2R_L - jR^2X_C - R^2R_Lh_{fe}]$$

$$= \underbrace{[R^3 + 3R^2R_L - 5RX_C^2 - R_LX_C^2 + R^2R_Lh_{fe}]}_{Re[\Delta]} + j\underbrace{[-6R^2X_C - 4RR_LX_C + X_C^3]}_{Im(\Delta)} \quad \dots (6.4.5)$$

For $\Delta = 0$ both its real and imaginary part must be equal to zero setting $Im(\Delta) = 0$,

We have, $\quad -6R^2X_C - 4RR_LX_C + X^3_C = 0$

$$\Rightarrow \quad X^2_C = 6R^2 + 4RR_L$$

$$\Rightarrow \quad \frac{1}{\omega^2c^2} = 6R^2 + 4RR_L \qquad (\because X_C = 1/\omega c)$$

$$\Rightarrow \quad \omega^2c^2 = \frac{1}{6R^2 + 4RR_L} \quad \dots (6.4.6)$$

$$\Rightarrow \quad \omega^2 = \frac{1}{c^2}\left[\frac{1}{6R^2 + 4RR_L}\right]$$

$$\Rightarrow \quad \omega = \sqrt{\frac{1}{c^2R^2}\left[\frac{1}{6 + \frac{4R_L}{R}}\right]} = \frac{1}{CR\sqrt{6 + \frac{4R_L}{R}}}$$

$$\therefore \quad f = \frac{1}{2\pi cR\sqrt{6 + \frac{4R_L}{R}}} \qquad (\because \omega = 2\pi f) \quad \dots (6.4.7)$$

Let $n = \frac{R_L}{R}$

$$\therefore \quad \boxed{f = \frac{1}{2\pi cR\sqrt{6 + 4n}}}$$

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6.4.1.4 Conditions for Sustained Oscillations

Setting real part of Δ i.e., $Re(\Delta) = 0$ from Eq. (6.4.5), we have,

$$R^3 + 3R^2R_L - 5RX^2_C - R_LX^2_C + R^2R_Lh_{fe} = 0$$

$$\Rightarrow \quad R^3 + R^2R_L(3 + h_{fe}) - 5RX^2_C - R_LX^2_C = 0$$

$$\Rightarrow \quad R^3 + R^2R_L(3 + h_{fe}) = X^2_C(5R + R_L)$$

$$R^3 + R^2R_L(h_{fe} + 3) = \frac{5R + R_L}{\omega^2 c^2} \qquad \left(\because X_C = \frac{1}{\omega C}\right) \qquad \text{... (6.4.8)}$$

Substituting the value of ω^2c^2 from Eq. (6.4.6) in Eq. (6.4.8), we have,

$$R^3 + R^2R_L(h_{fe} + 3) = \frac{5R + R_L}{\left(\frac{1}{6R^2 + 4RR_L}\right)}$$

$$\Rightarrow \quad R^3 + R^2R_L(h_{fe}+3) = (5R + R_L)(6R^2 + 4RR_L)$$

$$\Rightarrow \quad R^3 + R^2R_L(h_{fe}+3) = 30R^3 + 20R^2R_L + 6R^2R_L + 4RR_L^2$$

$$\Rightarrow \quad R^2 R_L(h_{fe}+3) = 29R^3 + 26R^2R_L + 4RR_L^2$$

$$\Rightarrow \quad h_{fe} = \frac{29R^3 + 26R^2R_L + 4RR_L^2}{R^2R_L} - 3$$

$$\Rightarrow \quad h_{fe} = \frac{29R^3 + 26R^2R_L + 4RR^2_L - 3R^2R_L}{R^2R_L} = \frac{29R^3 + 23R^2R_L + 4RR_L^2}{R^2R_L}$$

$$\therefore \quad \boxed{h_{fe} = 29\frac{R}{R_L} + 23 + \frac{4R_L}{R}}$$

Since we have assumed that, $n = \frac{R_L}{R}$

$$\therefore \quad \boxed{h_{fe} \geq \frac{29}{n} + 23 + 4n} \qquad \text{... (6.4.9)}$$

6.4.1.5 Minimum Value of h_{fe} for the Oscillations

We get the minimum value of h_{fe} when derivative of h_{fe} w.r.t to 'n' is zero. That is,

$$\frac{dh_{fe}}{dn} = 0$$

$$\Rightarrow \quad \frac{d}{dn}\left[\frac{29}{n} + 23 + 4n\right] = 0$$

$$\Rightarrow \quad \frac{-29}{n^2} + 4 = 0$$

$$\Rightarrow \quad n^2 = \frac{29}{4}$$

$$\therefore \quad n = 2.692$$

Substituting n = 2.692 in Eq. (6.4.9), we get,

$$h_{fe,min} = \frac{29}{2.692} + 23 + 4(2.692)$$

$$\therefore \quad \boxed{h_{fe,\ min} = 44.54} \qquad \dots (6.4.10)$$

COMMENT : *To get the sustained oscillations. We must select a transistor having h_{fe}, minimum of 44.54.*

EXAMPLE PROBLEM 1

Determine the frequency of oscillations when a RC phase-shift oscillator has R = 10 kΩ, C = 0.01 μF and R_C = 2.2 kΩ. Also, find the minimum current gain needed for this purpose.

SOLUTION

Given Data : R = 10 kΩ

C = 0.01 μF and R_C = 2.2 kΩ

The frequency of oscillations of RC phase-shift oscillator is,

$$f_o = \frac{1}{2\pi RC\sqrt{6 + \left(\frac{4R_C}{R}\right)}}$$

Substituting the given values, we get,

$$f_o = \frac{1}{2 \times 3.142 \times 10 \times 10^3 \times 0.01 \times 10^{-6}\sqrt{6 + \frac{4 \times 2.2 \times 10^3}{10 \times 10^3}}} = 607 \text{ Hz}$$

For sustained oscillations, the minimum value of current gain or forward current gain ratio h_{fe} is,

$$\beta = h_{fe} = 23 + \frac{29}{n} + 4n = 23 + 29\frac{R}{R_C} + \frac{4R_C}{R} \qquad \left(\because n = \frac{R_L}{R}\right)$$

$$\therefore \quad \beta = 23 + 29 \times \frac{10 \times 10^3}{2.2 \times 10^3} + 4 \times \frac{2.2 \times 10^3}{10 \times 10^3} = 155.69$$

6.4.1.6 Advantages and Disadvantages of RC Phase Shift Oscillators

Advantages of Phase Shift Oscillator : Following are the advantages of phase shift oscillator,

(1) It does not require transformers or inductors, that's why it is less bulky.

(2) Cheap and simple circuit as it contains resistors and capacitors only.

(3) Waveform is exceptionally pure and sinusoidal since the core saturation effect and harmonic distortion are absent as no transformer is used.

Disadvantages of Phase Shift Oscillator : Following are the disadvantages of phase shift oscillator,

(1) The main disadvantage of this circuit is the high gain requirement (approximately > 44.5) which is practically impossible.

(2) It gives only small output due to smaller feedback.

(3) Feedback is less and it is difficult for the circuit to start oscillations. This is because of high reactance of R and C.

(4) It requires high supply voltage i.e., $V_{CC} > 12$ V.

6.4.2 Wein Bridge Oscillators

Principle of Wein-bridge Oscillator is when the amplifier stage in the oscillator does not change phase of the input signal, the feedback network fed back to the input without producing any further phase shift. Wein-bridge oscillator finds extensive use in commercial audio generators in the frequency range from a few Hz to 1 MHz. The main advantage of this oscillator is that the frequency may be varied over a frequency range 1:10, whereas in RC oscillators frequency cannot be varied. The circuit diagram of Wein-bridge oscillator is shown as in Fig. 6.4.5,

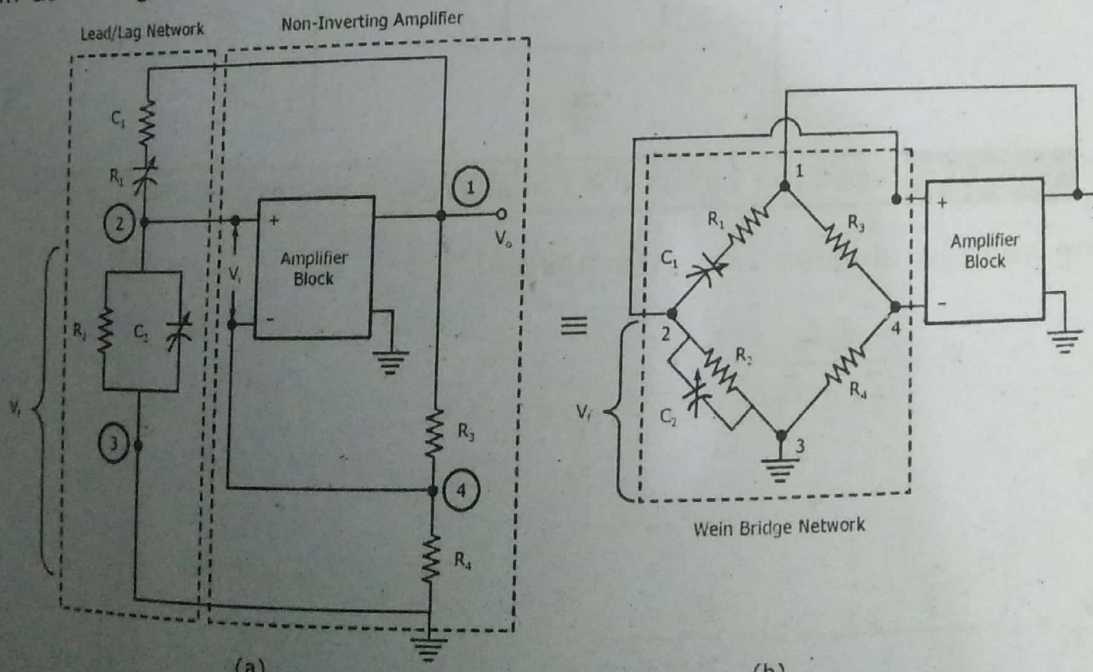


Fig. 6.4.5 Circuit Diagram of Wein-bridge Oscillator

As shown in Fig. 6.4.5(a), Wein bridge oscillator consists of an amplifier block, which produces an output without any phase shift. In this circuit, the resistors R_3 and R_4 provides the desired negative feedback. Apart from this resistors, it consists of a positive feedback circuit called a lead-lag network. The lead-lag network consists of two reactive arms that contain two RC networks, one of which is in shunt (i.e., R_2, C_2) and the other is in series (i.e., R_1, C_1). The R_1C_1 network form lag portion of the circuit and R_2C_2 network form lead portion of the circuit.

We can have a continuous variation of frequency in this oscillator by varying the two capacitors C_1 and C_2 simultaneously. These capacitors are variable air-ganged capacitors. We can change the frequency range of the oscillator by switching into the circuit different values of resistors R_1 and R_2. Circuit in Fig. 6.4.5(a) is redrawn with its position intact to show the presence of a "bridge" in Wein bridge oscillator, as shown in Fig. 6.4.5(b).

6.4.2.1 Frequency of Oscillations

The frequency of oscillation in Wein-bridge oscillator is obtained by considering the lead-lag circuit as shown in Fig. 6.4.6 since this circuit contains frequency sensitive elements (C_1, C_2).

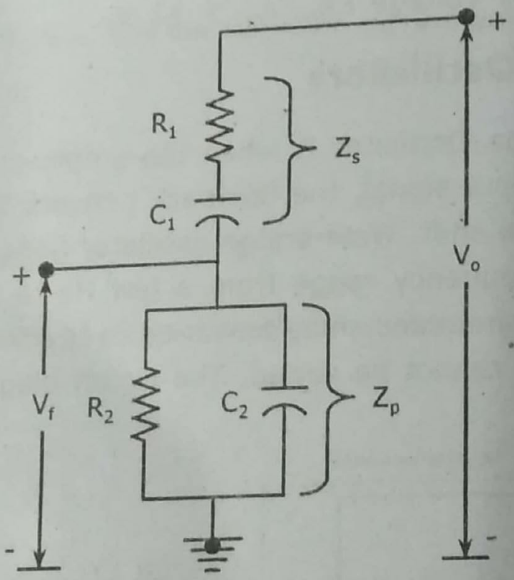


Fig. 6.4.6 Lead-log Circuit for Calculating Frequency of Oscillation

Applying voltage division rule, we have

$$V_f = \frac{V_o Z_p}{Z_s + Z_p} \qquad \text{... (6.4.11)}$$

Where,

$$Z_p = \frac{\left[R_2 \cdot \frac{1}{j\omega C_2}\right]}{\left[R_2 + \frac{1}{j\omega C_2}\right]} = \frac{R_2}{1 + j\omega R_2 C_2} \qquad \text{... (6.4.12)}$$

And $Z_s = R_1 + \frac{1}{j\omega C_1} = \frac{j\omega R_1 C_1 + 1}{j\omega C_1}$ ... (6.4.13)

Substituting Eqs. (6.4.12) and (6.4.13) in Eq. (6.4.11), we have,

$$V_f = V_o \left[\frac{(R_2 / 1 + j\omega R_2 C_2)}{\frac{R_2}{1 + j\omega R_2 C_2} + \frac{j\omega R_1 C_1 + 1}{j\omega C_1}} \right]$$

$$V_f = V_o \left[\frac{j\omega R_2 C_1}{j\omega R_2 R_1 + 1 + j\omega R_1 C_1 + j\omega R_2 C_2 - \omega^2 R_1 R_2 C_1 C_2} \right]$$

$\therefore$
$$\beta = \frac{V_f}{V_o} = \frac{j\omega R_2 C_1}{1 + j\omega R_2 C_1 + j\omega R_1 C_1 + j\omega R_2 C_2 - \omega^2 R_1 R_2 C_1 C_2} \quad \text{... (6.4.14)}$$

In practise, $R_1 = R_2 = R$ and $C_1 = C_2 = C$. Using these values, Eq. (6.4.14) now becomes,

$\therefore$
$$\beta = \frac{j\omega RC}{1 + 3j\omega RC - \omega^2 R^2 C^2}$$

From Barkhausen's criteria, for sustained oscillations

$$|A\beta| = 1$$

$\Rightarrow$
$$A\left[\frac{j\omega RC}{1 + 3j\omega RC - \omega^2 R^2 C^2}\right] = 1$$

$\Rightarrow$
$$1 + 3j\omega RC - \omega^2 R^2 C^2 = Aj\omega RC \quad \text{... (6.4.15)}$$

Equating imaginary parts on both sides of Eq. (6.4.15), we have,

$$3j\omega RC = Aj\omega RC$$

$\therefore$
$$\boxed{A = 3}$$

Thus the gain of the amplifier should be 3 for sustained oscillations.

Equating real parts on both sides of Eq. (6.4.15), we have,

$$1 - \omega^2 R^2 C^2 = 0$$

$\Rightarrow$
$$\omega R^2 C^2 = 1$$

$\Rightarrow$
$$\omega = \frac{1}{RC}$$

$\therefore$
$$\boxed{f = \frac{1}{2\pi RC}} \quad \text{... (6.4.16)}$$

Eq. (6.4.16) gives the frequency of oscillations for a Wien bridge oscillator.

Condition for Bridge which to be Balanced : The bridge is said to be balanced when,

$$\frac{R_3}{R_4} = \frac{(R_1 + 1/j\omega C_1)}{(R_2/1 + j\omega R_2 C_2)}$$

Using $R_1 = R_2 = R$ and $C_1 = C_2 = C$, we have

$$\frac{R_3}{R_4} = \frac{(R + 1/j\omega C)}{(R/1 + j\omega RC)} = \frac{[(j\omega RC + 1)/j\omega C]}{[R/(1 + j\omega RC)]}$$

$$= 2 + j\left[\frac{R^2 - 1/(\omega^2 C^2)}{R/(\omega C)}\right] \quad \text{... (6.4.17)}$$

Equating the real parts on the both sides of Eq. (6.4.17), we get,

$$\therefore \quad \boxed{\frac{R_3}{R_4} = 2} \quad \text{... (6.4.18)}$$

6.4.2.2 Wein-Bridge Oscillator Using BJTS

The Fig. 6.4.7 shows the Wein-bridge oscillator using transistors. The two stage RC coupled amplifier, provides an approximately 360° or 0° phase-shift. So the feedback network has no need to introduce any additional phase-shift. The feedback network consists of $C_1 - R_1$, $C_2 - R_2$ (called a lead-lag network) and $R_3 - R_4$ (called a voltage divider). The lead-lag network provides a positive feedback to the input of the first stage and the voltage divider, the negative feedback to the emitter of Q_1 transistor.

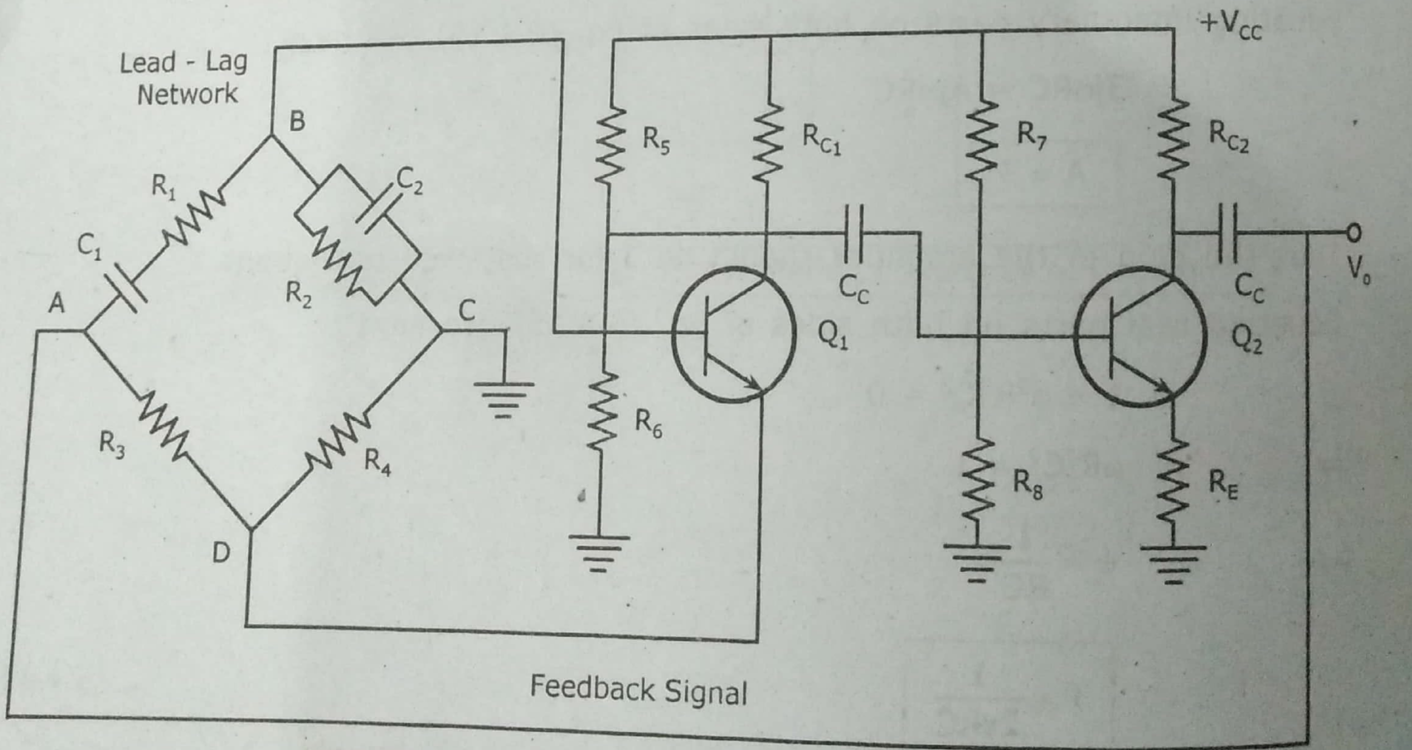


Fig. 6.4.7 Weinbridge Oscillator using Transistors

The oscillator frequency can be varied by varying two capacitors C_1 and C_2 simultaneously. These are variable airgang capacitors. The frequency range of the oscillator can be changed by switching the different preset values of resistors R_1 and R_2 into the circuit. On the other hand, in a transistor wein-bridge oscillator, because of the low input resistance of transistor, the range changes are made by switching in the preset values of capacitors C_1 and C_2. For continuous frequency variation, the values of resistors R_1 and R_2 are changed by using a dual potentiometer.

When the circuit is energized by switching on the supply, a small random oscillations appearing at the base of Q_1 transistor are amplified, at its collector. These oscillations are further amplified at the collector of Q_2 transistor. Since the oscillations at the collector of Q_2 transistor have been inverted twice, therefore these oscillations are in phase with the input signal. A part of the output signal from the collector of Q_2 transistor is feedback to the wein-bridge, which is further amplified. The process continues, till sustained oscillations are produced.

6.4.2.3 Advantages and Disadvantages of Wein Bridge Oscillator

Advantages : The Wien bridge oscillator has the following advantages,

(1) The overall gain is high since a two-stage amplifier is used.

(2) The circuit gives a exceedingly good sine wave output.

(3) The frequency of oscillation can be easily varied.

(4) This gives a good frequency stability, i.e., the frequency of oscillation remains constant over a fairly long time interval. This is because the frequency is dependent on R and C. If the passive elements R and C are kept fixed particularly by monitoring against temperature variations, frequency stability can be achieved.

(5) Amplitude stability of oscillator output can be increased, this is achieved by replacing resistor R_4 with a thermistor.

Disadvantages : The wein bridge oscillator has the following disadvantages,

(1) It cannot generate very high frequencies.

(2) Large number of components are needed for two stage transistor amplifier.

EXAMPLE PROBLEM 6.4

In the Wien-bridge oscillator $R_1 = R_2 = 220k\Omega$ and $C_1 = C_2 = 250pF$. Determine the frequency of oscillations.

SOLUTION

Given Data : $R_1 = R_2 = R = 200k\Omega = 220 \times 10^3\Omega$

$C_1 = C_2 = C = 250pF = 250 \times 10^{-12}F$

Frequency of oscillations in a Wein-bridge oscillator given as,

$$f = \frac{1}{2\pi RC}$$

$$= \frac{1}{2\pi \times 220 \times 10^3 \times 250 \times 10^{-12}} \text{ Hz}$$

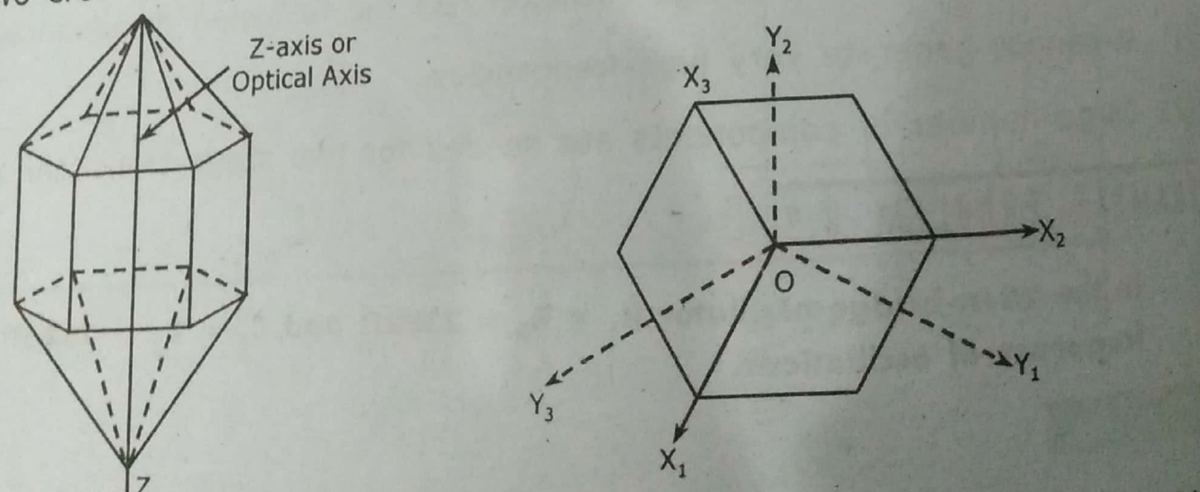
$$= 2895.19 \text{ Hz.}$$

6.5 CRYSTAL OSCILLATOR

In Hartley and Colpitts oscillators, we have found that the tank circuit parameters determine the frequency of oscillation. Such parameter values can change with time, climate and temperature fluctuations. Therefore, the frequency of oscillation does not remain constant. For a high frequency stability, LC oscillators are therefore unsuitable. The resonant frequencies of some naturally available crystals, like quartz, are relatively constant. So, for a high frequency stability, a crystal is employed as the frequency-determining element in an oscillator. Such oscillators are referred to as crystal oscillators.

A crystal oscillator is basically a tuned circuit oscillator using a piezoelectric crystal as a resonant tank circuit. The crystal (usually-Quartz) has a great stability in holding constant at whatever frequency the crystal is originally cut to operate. Crystal oscillator are used whenever great stability is required, for example in communication transmitter and receivers. The principle of crystal oscillators depends upon piezoelectric effect.

Characteristics of Quartz Crystal : A quartz crystal is generally in the form of a thin uniform plate or wafer of usually rectangular shape, cut from the natural quartz crystal shown in Fig. 6.5.1 (a). The electrical properties of such a quartz crystal plate depends on the size of crystal and its orientation relative to the three sets of axes of crystal and its orientation relative to the three sets of axes of the natural crystal, known as the Z, Y and X axes which are at right angles to each other. The Z-axis or the optical axis is one joining the two crowns or the pointed ends of the natural crystal.



(a) Natural Quartz Crystal (b) Section of Quartz Crystal Perpendicular to Z-axis

Fig. 6.5.1 Natural Quartz Crystal and Three Sets of Axes

Fig. 6.5.1(b) shows a section of the crystal at right angles to the Z-axis. This cross-section is an irregular hexagon in which each side makes an angle of 120° with its adjacent sides. Fig. 6.5.1(b) shows the three axes OX_1, OX_2 and OX_3 parallel to the faces of the crystal. These axes form the X-axis or the electrical axes. In a regular hexagon (assumed here), these X-axes pass through the corners of the hexagon. The three axes OY_1, OY_2 and OY_3 perpendicular to the faces of the crystal form the Y-axis or the mechanical axes. Each mechanical axis is at right angles to the respective electrical axis.

A material is said to show piezo-electric effect if a mechanical stress applied to it produces electric charges and hence difference of potential and conversely when placed in an electric field, these result mechanical strain and distortion.

Thus in a quartz crystal, if an electric field is applied in the direction of an X-axis or electric axis, a mechanical strain is produced in the direction of the corresponding Y-axis. Conversely if a mechanical stress is applied along a Y-axis, electric charges appear on the faces of the crystal perpendicular to the corresponding X-axis.

The polarity of the electric stress and the direction of the corresponding mechanical stress have direct relation. Thus if the direction of the electric stress is reversed, the direction of the corresponding mechanical force also reverses.

Frequency of Crystal : Each crystal has a natural frequency like a pendulum. The natural frequency f of a crystal is given by, $f = \frac{k}{t}$ where K is a constant that depends upon the cut and t is the thickness of the crystal. It is clear that frequency is inversely proportional to crystal thickness. The thinner the crystal, the greater is its natural frequency and vice-versa. However, extremely thin crystal may break because of vibrations. This puts a limit to the frequency obtainable.

WORKING OF QUARTZ CRYSTAL

In order to use crystal in an electronic circuit, it is placed between two metal plates. The arrangement then forms a capacitor with crystal as the dielectric as shown in Fig. 6.5.2. If an A.C voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage.

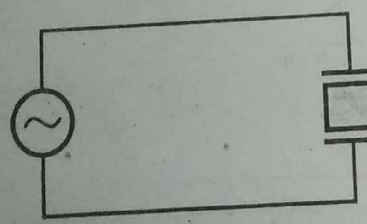


Fig. 6.5.2 Crystal Circuit

However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value. This natural frequency is almost constant. Effects of temperature change can be eliminated by mounting the crystal in a temperature controlled over as in radio and television transmitters.

6.5.1 Equivalent Circuit of Crystal

(1) When the crystal is not vibrating, it is equivalent to capacitance C_m because it has two metal plates separated by a dielectric as shown in Fig. 6.5.3(a). This capacitance is known as mounting capacitance (C_m).

(2) When, a crystal vibrates, it is equivalent to R-L-C series circuit as shown in Fig. 6.5.3(b). Therefore, the equivalent circuit of a vibrating crystal is R-L-C series circuit shunted by the mounting capacitance 'C_m'.

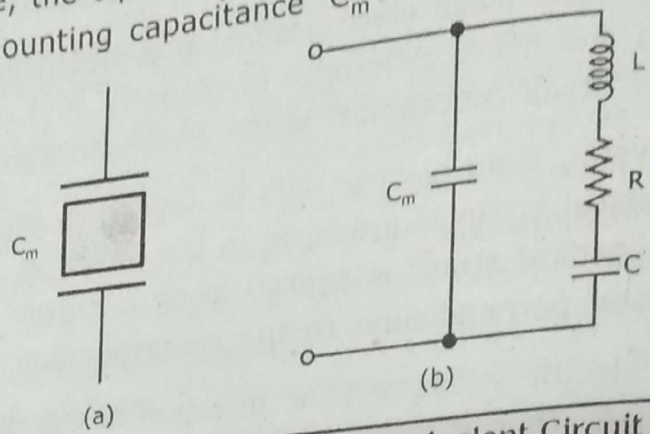


Fig. 6.5.3 Crystal and its Equivalent Circuit

The circuit shown in Fig. 6.5.3(b) has two following frequencies,

(1) Series Resonant Frequency (f_s) : This occurs when $X_L = X_C$

$$\Rightarrow \quad \omega L = \frac{1}{\omega C}$$

$$\Rightarrow \quad \omega^2 LC = 1$$

$$\Rightarrow \quad \omega = \frac{1}{\sqrt{LC}}$$

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

(2) Parallel Resonant Frequency (f_p) : This occurs when $X_L + X_C = X_{C_m}$

$$\Rightarrow \quad \omega L - \frac{1}{\omega C} = \frac{1}{\omega C_m}$$

$$\Rightarrow \quad \omega L = \frac{1}{\omega C} + \frac{1}{\omega C_m}$$

$$\Rightarrow \quad \omega^2 L = \frac{C + C_m}{CC_m}$$

$$\Rightarrow \quad \omega = \sqrt{\frac{C + C_m}{CC_m . L}}$$

$$\therefore \quad \boxed{f_p = \frac{1}{2\pi}\sqrt{\frac{C + C_m}{CC_m . L}}}$$

At this frequency, crystal circuit offers a very high impedance to external circuit.

The frequency versus impedance graph is shown in Fig. 6.5.4,

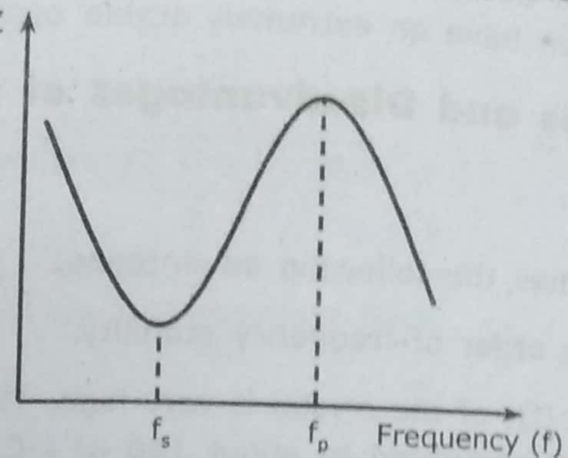


Fig. 6.5.4 Frequency Vs Impedance Graph of Crystal

At frequencies greater than f_p, the value of X_{C_m} drops and eventually the crystal acts as a short circuit.

6.5.2 Transistorized Crystal Oscillator

Fig. 6.5.5 shows the transistor crystal oscillator.

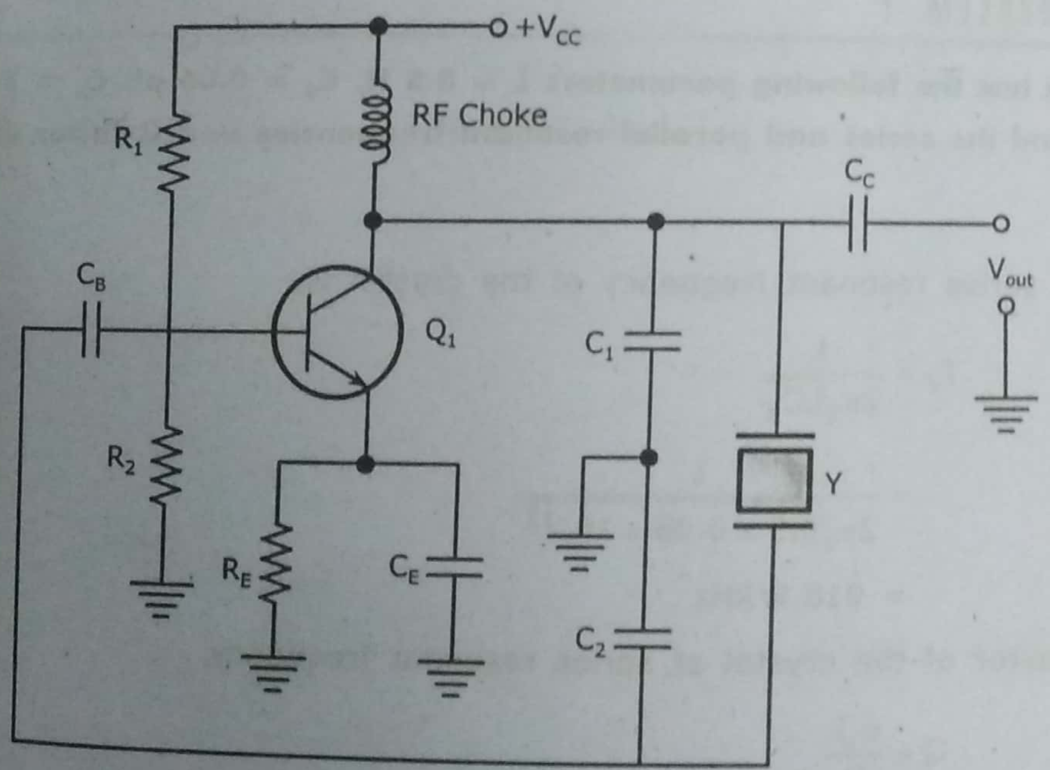


Fig. 6.5.5 Transistor Crystal Oscillator Circuit

The crystal will act as a parallel-tuned circuit. At parallel resonance, the impedance of the crystal is maximum. This means that there is a maximum voltage drop across C_1. This in turn will allow the maximum energy transfer through the feedback network at f_p.

The feedback is positive. A phase shift of 180° is produced by the transistor. A further phase shift of 180° is produced by the capacitor voltage. This oscillator will oscillate only at f_p. Even the smallest deviation from f_p will cause the oscillator to act as an effective short. Consequently, we have an extremely stable oscillator.

6.5.3 Advantages and Disadvantages of Crystal Oscillators

ADVANTAGES

The crystal oscillator has the following advantages,

(1) They have a high order of frequency stability.

(2) The quality factor (Q) of the crystal is very high. The Q factor of the crystal may be as high as 10,000 compared to about 100 of L-C tank.

DISADVANTAGES

The crystal oscillator has the following disadvantages,

(1) They are fragile and consequently can only be used in low power circuits.

(2) The frequency of oscillations cannot be changed appreciably.

EXAMPLE PROBLEM 1

A crystal has the following parameters L = 0.5 H, C_s = 0.06 pF, C_p = 1 pF and R = 5 kΩ. Find the series and parallel resonant frequencies and Q-factor of the crystal.

SOLUTION

(a) The series resonant frequency of the crystal is,

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

$$= \frac{1}{2\pi\sqrt{0.5 \times 0.06 \times 10^{-12}}}$$

$$= 918.9 \text{ kHz}$$

Q factor of the crystal at series resonant frequency,

$$Q = \frac{\omega_s L}{R}$$

$$= \frac{2\pi f_s L}{R}$$

$$= \frac{2\pi \times 918.9 \times 10^3 \times 0.5}{5 \times 10^3}$$

$$= 577$$

(b) The parallel resonant frequency of the crystal is,

$$f_p = \frac{1}{2\pi}\sqrt{\frac{C_s + C_p}{LC_sC_p}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{1.06 \times 10^{-12}}{0.5 \times 0.06 \times 10^{-12} \times 1 \times 10^{-12}}}$$

$$= 946 \text{ kHz}$$

Q factor of the crystal at parallel resonant frequency,

$$Q = \frac{\omega_p L}{R}$$

$$= \frac{2\pi f_p L}{R}$$

$$= \frac{2\pi \times 946 \times 0.5}{5 \times 10^3}$$

$$= 594$$

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