OSCILLATORS

Introduction :-

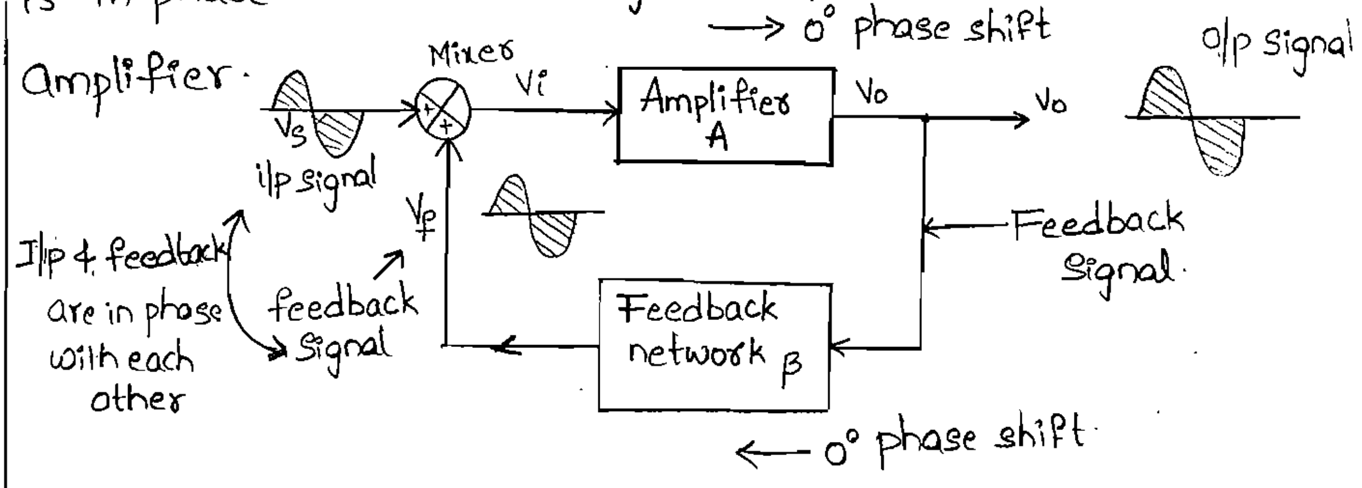
The Operation of the feedback amplifiers in which the negative feedback is used, has been discussed earlier. In this chapter, a device which works on the principle of positive feedback is discussed. The device is called an 'Oscillator'.

An Oscillator does not require any input signal. It can generate a voltage of any desired waveform at any frequency. It 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 added to the amplifier.



Assume that a sinusoidal input signal (Voltage) V_s is applied to the circuit. As amplifier is non-inverting, the output voltage V_o is in phase with the input signal V_s. The part of the output is fedback to the input with the help of a feedback network.

How much part of the output is to be fedback, gets decided by the feedback network gain β. No phase change is introduced by the feedback network. Hence the feedback Voltage V_f is in phase with the input signal V_s.

The Amplifier gain is A_v

$$A_v = \frac{V_o}{V_i}$$

This is called open loop gain of the amplifier

The Overall circuit gain is A_{vf}

$$A_{vf} = \frac{V_o}{V_s}$$

The feedback is positive and the Voltage V_f is added to V_s to generate input of amplifier V_i

$$\Rightarrow V_i = V_s + V_f$$

$$V_f = \beta V_o$$

$$\Rightarrow V_i = V_s + \beta V_o$$

$$\Rightarrow V_s = V_i - \beta V_o$$

$$V_o = A_v V_i$$

$$\Rightarrow V_s = V_i - \beta (A_v V_i)$$

$$\Rightarrow V_s = V_i - V_i \beta A_v$$

$$\Rightarrow V_s = V_i (1 - \beta A_v)$$

$$\Rightarrow \frac{V_i}{V_s} = \frac{1}{1-\beta A_v}$$

The Overall Circuit gain $A_{vf} = \frac{V_o}{V_s}$

$$= \frac{V_o}{V_i} \times \frac{V_i}{V_s}$$

$$= A_v \cdot \frac{1}{1-\beta A_v}$$

$$\boxed{A_{vf} = \frac{A_v}{1-\beta A_v}}$$

Thus Without an input, the output will Continue to Oscillate whose frequency depends upon the feedback network or the amplifier or both.

Differences b/w positive and Negative Feedback :-

Positive feedback	Negative feedback
1. When the feedback applied is such that it is in phase with the original input signal then it is called positive	1. When the feedback applied is such that it is out of phase with the original i/p signal then it is called negative.
2. It increases the gain of the amplifier	2. It decreases the gain of the amplifier
3. It is regenerative or direct feedback	3. It is degenerative or inverse feedback.
4. It makes the amplifier unstable	4. It makes the Amplifier stable.
5. It reduces the Bandwidth	5. It increases in Bandwidth
6. It is used in the Oscillators	6. It is used in the Small Signal amplifiers.

Conditions for Oscillations :-
(or)
Barkhausen Criterion :-

Consider a basic inverting amplifier with an open loop gain A_v. The feedback network attenuation factor β is less than unity. As basic amplifier is inverting, it produces a phase shift of 180° b/w i/p and o/p as shown in below figure.

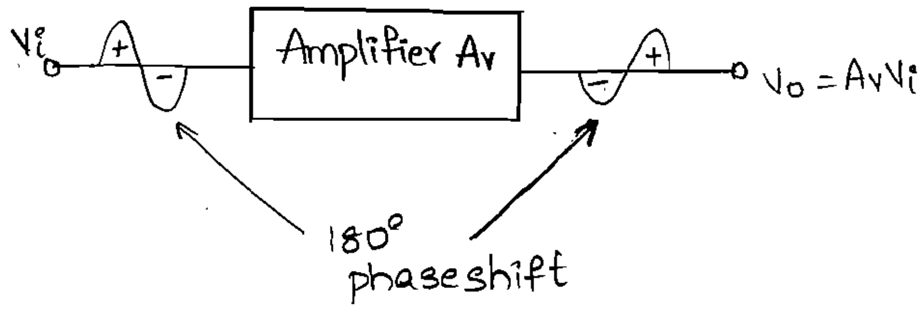


fig: Inverting amplifier.

Now, the input V_i applied to the amplifier is to be derived from its output V_o using feedback network. Since, it is positive feedback, the voltage derived from output using feedback network must be in phase with V_i. Thus the feedback network must ~~go~~ introduce a phase shift of 180° while feeding back the voltage from output to input.

Consider the basic block diagram of oscillator circuit

As $$A_v = \frac{-V_o}{V_i}$$

$$\beta = -\frac{V_f}{V_o}$$

Here, $-ve$ Sign indicates $180°$ phase shift between input and output.

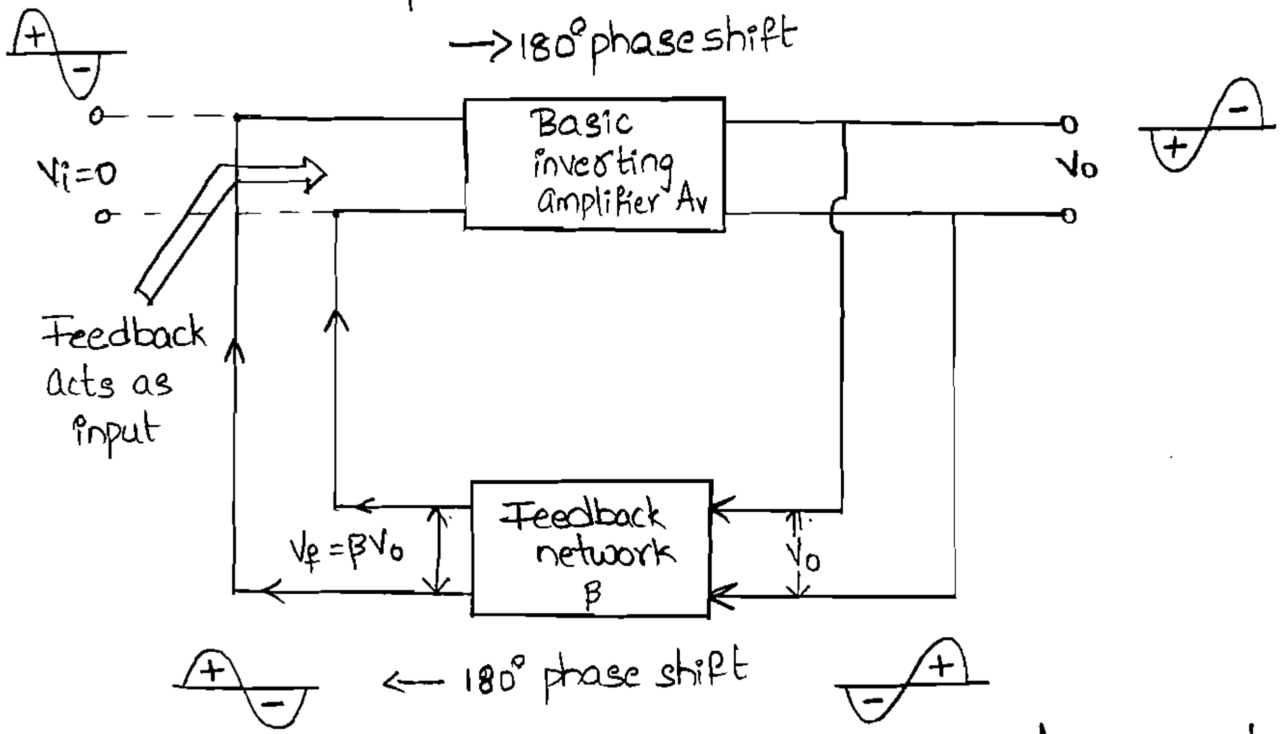


Fig: Basic block diagram of Oscillator circuit

From above figure,

$\Rightarrow V_f = -\beta V_o$ $\quad [A_v = -V_o/V_i$

$\Rightarrow V_f = -\beta(-A_v V_i)$ $\quad V_o = -A_v V_i]$

$\Rightarrow V_f = \beta A_v V_i$

For the Oscillator, the feedback should drive the amplifier and hence V_f must act as V_i i.e., $V_f = V_i$

$1 = \beta A_v$

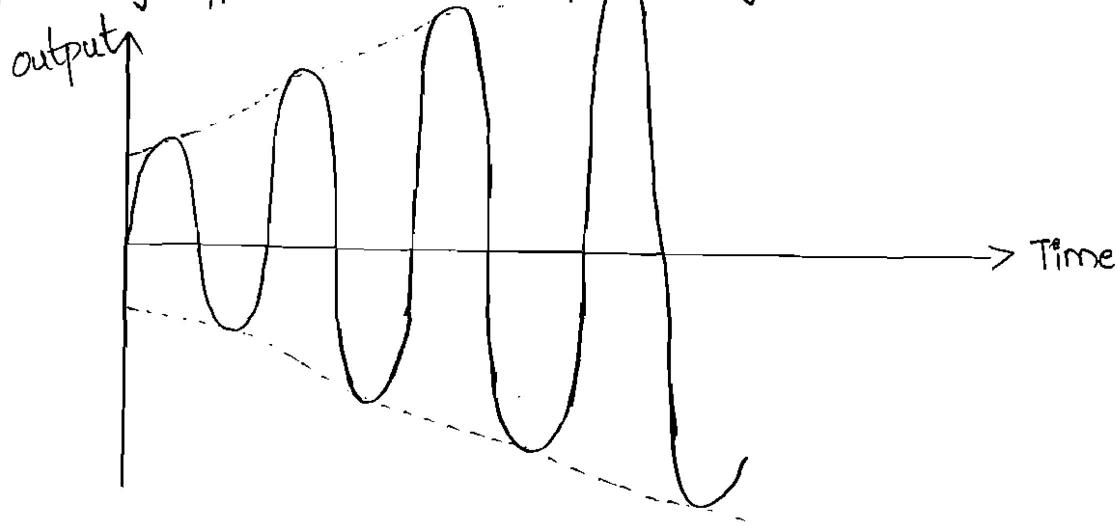
$$\boxed{|A_v \beta| = 1}$$

The total phase shift around a loop is $360°$.

Let us consider the effect of the magnitude of the product A_v and β on the nature of the oscillations.

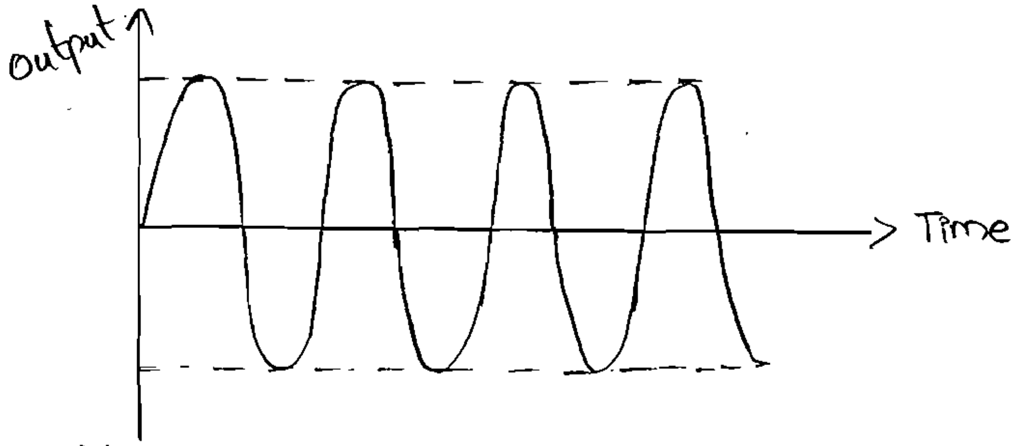
Case (i) :- $|A_v\beta| > 1$

When the total phase shift around a loop is $0°$ or $360°$ and $|A_v\beta| > 1$, then the o/p oscillates but the oscillations are of growing type i.e the amplitude goes on increases



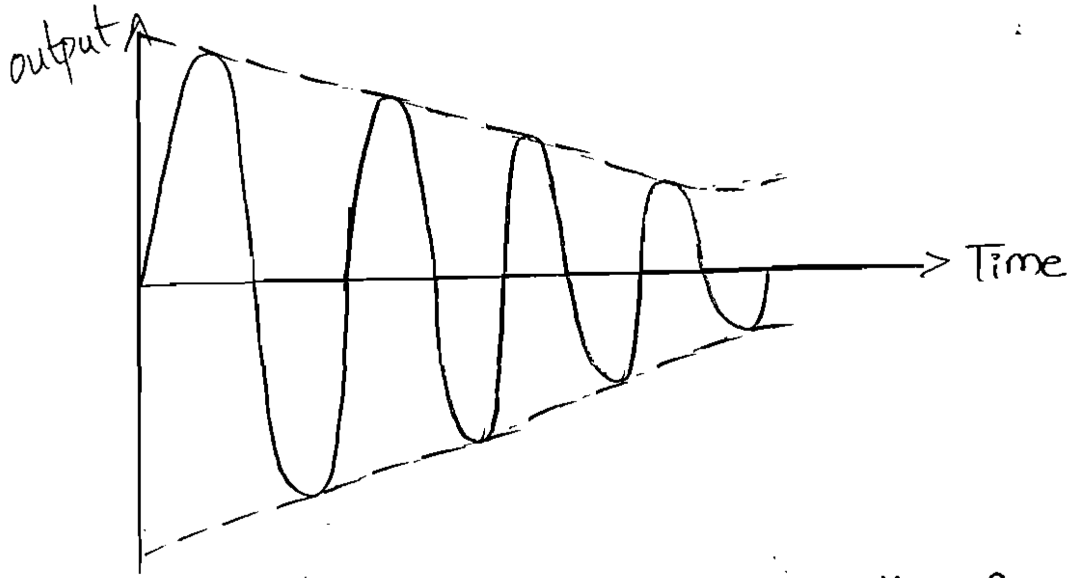
Case (ii) :- $|A_v\beta| = 1$

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



Case (iii) :- $|A_v\beta| < 1$

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



According to Barkhausen Criterion, the Conditions for Oscillations are

(i) The Overall phase shift across the closed loop should be equal to 0° (or) 360°.

(ii) The magnitude of product of open loop gain Amplifier (A_v) and the feedback factor (β) is unity i.e.,

$|A_v \beta| \leq 1$

<u>Types of Oscillators</u> :-

(1) Low frequency oscillators ($\leq 20KHz$)
  (a) RC phase shift Oscillator
  (b) Wein bridge oscillator

(2) High frequency oscillator (or) LC Oscillators ($> 20KHz$)
  (a) Hartley Oscillator
  (b) Colpitt's oscillator
  (c) clap Oscillator
  (d) Crystal Oscillator

RC phase shift Oscillator (BJT) :-

It Consists of a Conventional single transistor amplifier and RC phase shift network. the amplifier and phase shift network each provide 180° of phase shift. The phase shift network consists of three RC sections. At some particular frequency 'f' the phase shift in each RC section is 60° so that the total phase shift produced by the RC network is 180° and at this frequency the total phase shift from the base around the circuit will oscillate, provided the magnitude of the amplifier is sufficiently large.

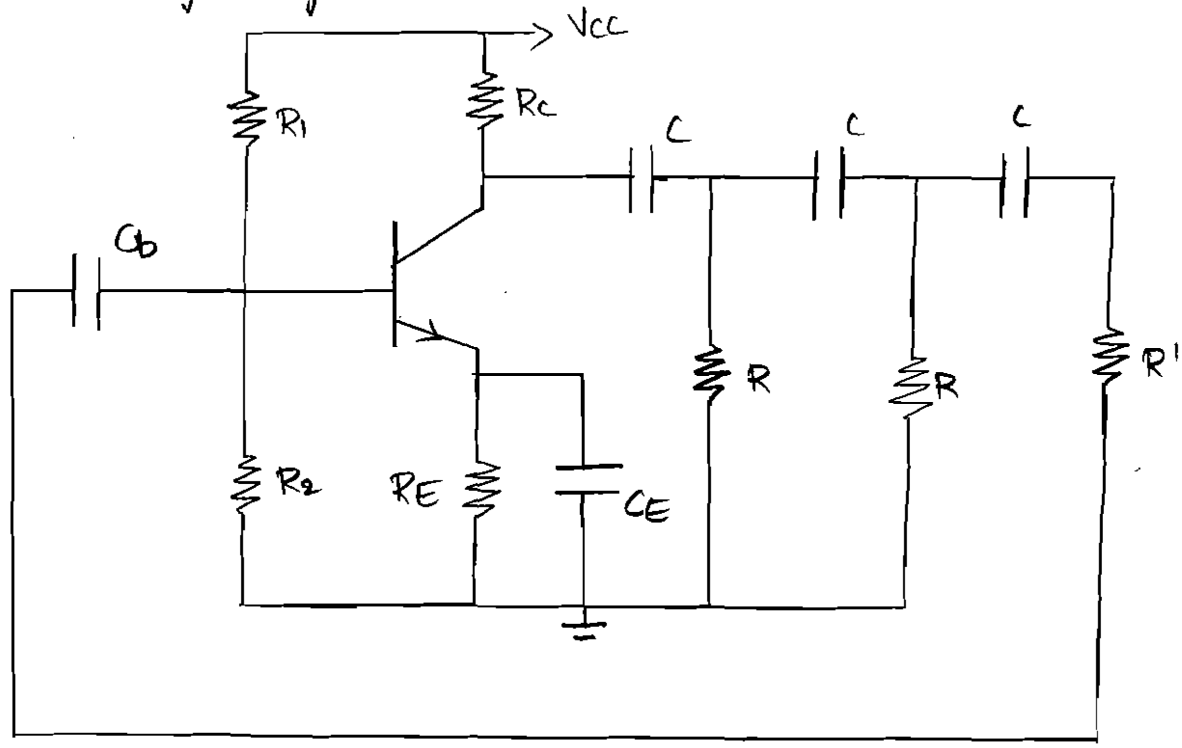
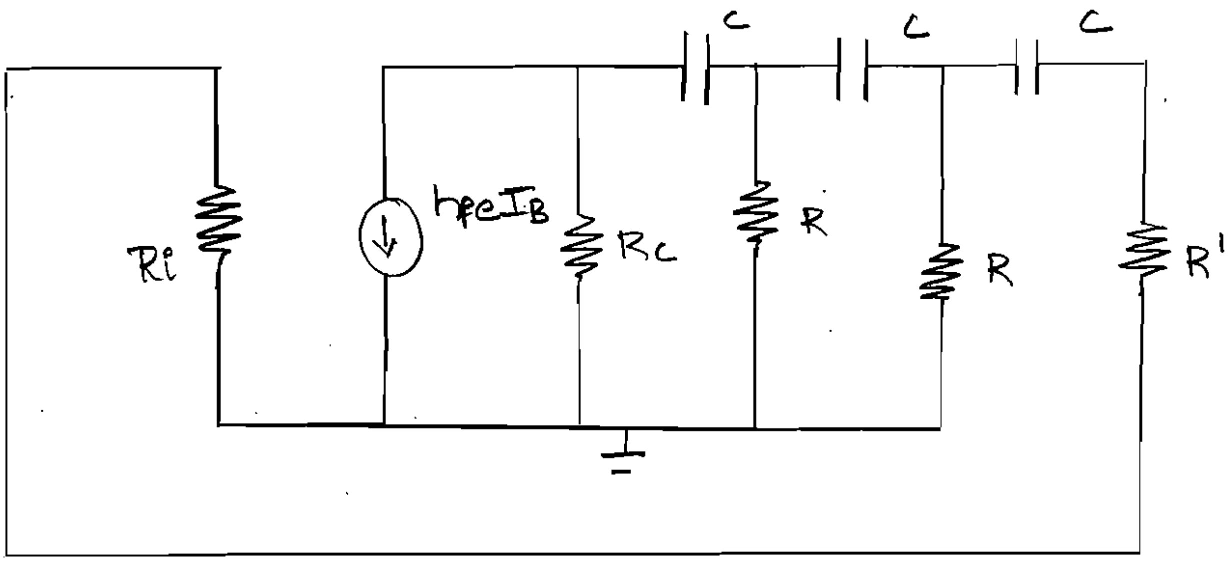
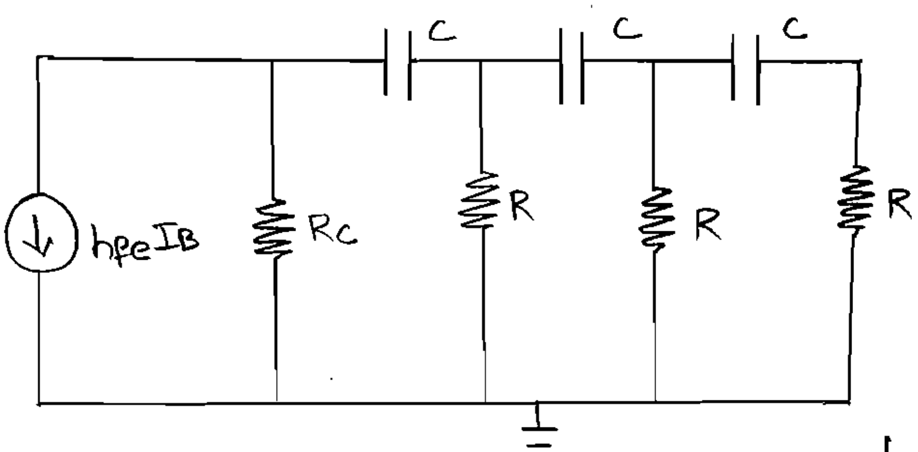


Fig: RC phase shift oscillator

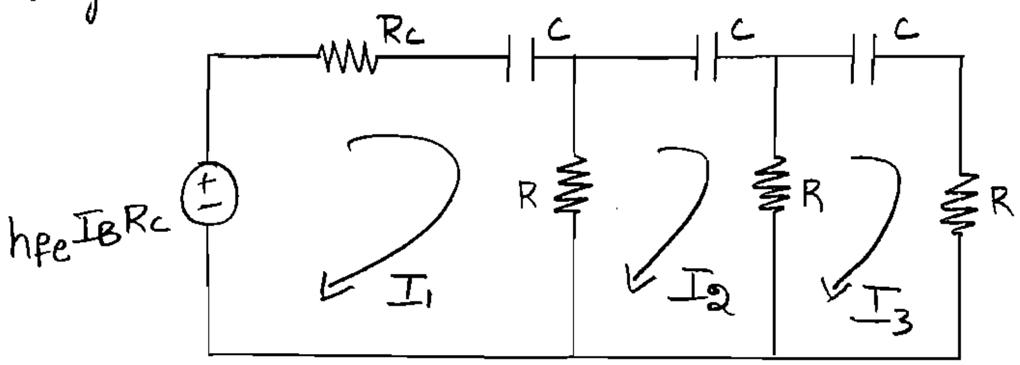
Replacing the transistor with its h-parameter Equivalent circuit



If $R_i + R' = R$ then the circuit can be redrawn as



Replacing the current source with respect to its Voltage source, then the circuit will be



From Barkhausen Criterion, we have

$$A\beta = 1$$

Where $A = \frac{V_o}{V_i}$, $\beta = \frac{V_f}{V_o}$

$$A\beta = 1$$

$$\frac{V_o}{V_i} \times \frac{V_f}{V_o} = 1$$

$$\frac{V_f}{V_i} = 1$$

From the circuit, we have

$$V_f = I_3 R \quad \text{and} \quad V_i = I_B R$$

$$\Rightarrow \frac{I_3 R}{I_B R} = 1$$

$$\boxed{\frac{I_3}{I_B} = 1} \rightarrow ①$$

Applying KVL to loop 1 in the circuit

$$-h_{fe} I_B R_C = I_1 R_C + I_1 X_C + (I_1 - I_2) R$$

$$-h_{fe} I_B R_C = I_1 R_C + I_1 X_C + I_1 R - I_2 R$$

$$-h_{fe} I_B R_C = I_1 (R_C + X_C + R) - I_2 R \rightarrow ②$$

Applying KVL to loop 2 in the circuit

$$0 = R(I_2 - I_1) + I_2 X_C + (I_2 - I_3) R$$

$$0 = R I_2 - R I_1 + I_2 X_C + I_2 R - I_3 R$$

$$0 = -I_1 R + I_2 (R + X_C + R) - I_3 R$$

$$0 = -I_1 R + I_2 (2R + X_C) - I_3 R \rightarrow ③$$

Applying KVL to loop 3 in the circuit

$$0 = R(I_3 - I_2) + I_3 X_C + I_3 R$$

$$0 = R I_3 - R I_2 + I_3 X_C + I_3 R$$

$$0 = -I_2 R + I_3(R+R+X_c)$$

$$0 = -I_2 R + I_3(2R+X_c) \rightarrow (4)$$

Apply Matrix format to Equations (2), (3) & (4)

$$\begin{bmatrix} -h_{fe} I_B R_c \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \begin{bmatrix} R_c+X_c+R & -R & 0 \\ -R & 2R+X_c & -R \\ 0 & -R & 2R+X_c \end{bmatrix}$$

$$I_3 = \frac{\begin{vmatrix} R_c+X_c+R & -R & -h_{fe} I_B R_c \\ -R & 2R+X_c & 0 \\ 0 & -R & 0 \end{vmatrix}}{\begin{vmatrix} R_c+X_c+R & -R & 0 \\ -R & 2R+X_c & -R \\ 0 & -R & 2R+X_c \end{vmatrix}}$$

$$I_3 = \frac{-h_{fe} I_B R_c (R^2 - 0)}{R_c+X_c+R\left[(2R+X_c)^2 - R^2\right] + R\left[-R(2R+X_c) - 0\right]}$$

$$I_3 = \frac{-h_{fe} I_B R_c R^2}{(R_c+X_c+R)\left[3R^2+X_c^2+4RX_c\right] + R\left[-2R^2 - RX_c\right]}$$

$$I_3 = \frac{-h_{fe} I_B R_c R^2}{3R^2 R_c + R_c X_c^2 + 4RR_c X_c + 3R^2 X_c + X_c^3 + 4RX_c^2 + 3R^3 + RX_c^2 + 4R^2 X_c - 2R^3 - R^2 X_c}$$

$$I_3 = \frac{-h_{fe} I_B R_C R^2}{3R^2R_C + R_C X_C^2 + 4RR_C X_C + 6R^2 X_C + X_C^3 + 5RX_C^2 + R^3}$$

$$\frac{I_3}{I_B} = \frac{-h_{fe} R_C R^2}{3R^2R_C + R_C X_C^2 + 4RR_C X_C + 6R^2 X_C + X_C^3 + 5RX_C^2 + R^3}$$

From (1), We have $\frac{I_3}{I_B} = 1$

$$\frac{-h_{fe} R_C R^2}{3R^2R_C + R_C X_C^2 + 4RR_C X_C + 6R^2 X_C + X_C^3 + 5RX_C^2 + R^3} = 1$$

$$-h_{fe} R_C R^2 = 3R^2R_C + R_C X_C^2 + 4RR_C X_C + 6R^2 X_C + X_C^3 + 5RX_C^2 + R^3$$

Substituting $X_C = \frac{1}{j\omega C} = \frac{-j}{\omega C}$

$$-h_{fe} R_C R^2 = 3R^2R_C + R_C\left(\frac{-j}{\omega C}\right)^2 + 4RR_C\left(\frac{-j}{\omega C}\right) + 6R^2\left(\frac{-j}{\omega C}\right) + \left(\frac{-j}{\omega C}\right)^3 + 5R\left(\frac{-j}{\omega C}\right)^2 + R^3$$

Note

$j^2 = -1$

$(-j)^2 = -1$

$(-j)^3 = (-j)^2 \cdot -j$
$= j$

$$-h_{fe} R_C R^2 = 3R^2R_C - \frac{R_C}{\omega^2C^2} - j\frac{4RR_C}{\omega C} - j\frac{6R^2}{\omega C} + \frac{j}{\omega^3C^3} - \frac{5R}{\omega^2C^2} + R^3$$

$$-h_{fe} R_C R^2 = 3R^2R_C - \frac{R_C}{\omega^2C^2} - \frac{5R}{\omega^2C^2} + R^3 - j\left[\frac{4RR_C}{\omega C} + \frac{6R^2}{\omega C} - \frac{1}{\omega^3C^3}\right]$$

By equating imaginary terms, We get frequency of RC phase shift Oscillator

$$\frac{4RR_C}{\omega C} + \frac{6R^2}{\omega C} - \frac{1}{\omega^3C^3} = 0$$

$$\frac{4RR_c}{\omega C}+\frac{6R^2}{\omega C}=\frac{1}{\omega^3C^3}$$

$$4RR_c+6R^2=\frac{1}{\omega^2C^2}$$

$$\omega^2C^2=\frac{1}{4RR_c+6R^2}$$

$$\omega C=\frac{1}{\sqrt{4RR_c+6R^2}}$$

$$\omega C=\frac{1}{\sqrt{R^2\left(6+\frac{4RR_c}{R^2}\right)}}$$

$$\omega C=\frac{1}{R\sqrt{\left(6+\frac{4R_c}{R}\right)}}$$

$$\omega=\frac{1}{RC\sqrt{6+4K}}$$

Where $K=\frac{R_c}{R}$

From $\omega=2\pi f$

$$\boxed{f=\frac{1}{2\pi RC\sqrt{6+4K}}}$$

By equating real terms, We can find the Condition for Av for Oscillations

$$-h_{fe}R_cR^2=3R^2R_c-\frac{R_c}{\omega^2C^2}-\frac{5R}{\omega^2C^2}+R^3$$

~~Multiplying LHS and RHS with K~~

$$-h_{fe}=3-\frac{1}{\omega^2C^2R}-\frac{5}{R\omega^2C^2R_c}+\frac{R}{R_c}$$

Multiplying LHS and RHS with K

$$-h_{fe}K = 3K - \frac{K}{\omega^2C^2R^2} - \frac{5K}{R\omega^2C^2R_C} + \frac{RK}{R_C}$$

$$-h_{fe}K = 3K - \frac{K}{\omega^2C^2R^2} - \frac{5}{\omega^2R^2C^2} + 1 \left[K = \frac{R_C}{R}\right]$$

As $\omega = \frac{1}{RC\sqrt{6+4K}}$

$$\omega RC = \frac{1}{\sqrt{6+4K}}$$

$$(\omega RC)^2 = \frac{1}{6+4K}$$

$$-h_{fe}K = 3K - K(6+4K) - 5(6+4K) + 1$$

$$= 3K - 6K - 4K^2 - 30 - 20K + 1$$

$$= -4K^2 - 23K - 29$$

$$\boxed{h_{fe}K = 4K^2 + 23K + 29} \rightarrow (5)$$

The gain of CE amplifier is given as

$$A_V = -h_{fe}\frac{R_C}{R}$$

$$A_V = -h_{fe}K$$

$$A_V = -(4K^2 + 23K + 29)$$

As $\frac{R_C}{R} = K$ is very small

$$A_V = -29$$

$$\boxed{|A_V| = 29}$$

As $A\beta = 1$

$$\beta = \frac{1}{A} \Rightarrow \boxed{\beta = \frac{1}{29}}$$

The minimum h_{fe} value required for the transistor is $\frac{dh_{fe}}{dk} = 0$

From ⑤ $\frac{d}{dk}\left[4k + 23 + \frac{29}{k}\right] = 0$

$$4 + 0 - \frac{29}{k^2} = 0$$

$$4 = \frac{29}{k^2}$$

$$k = \frac{\sqrt{29}}{2}$$

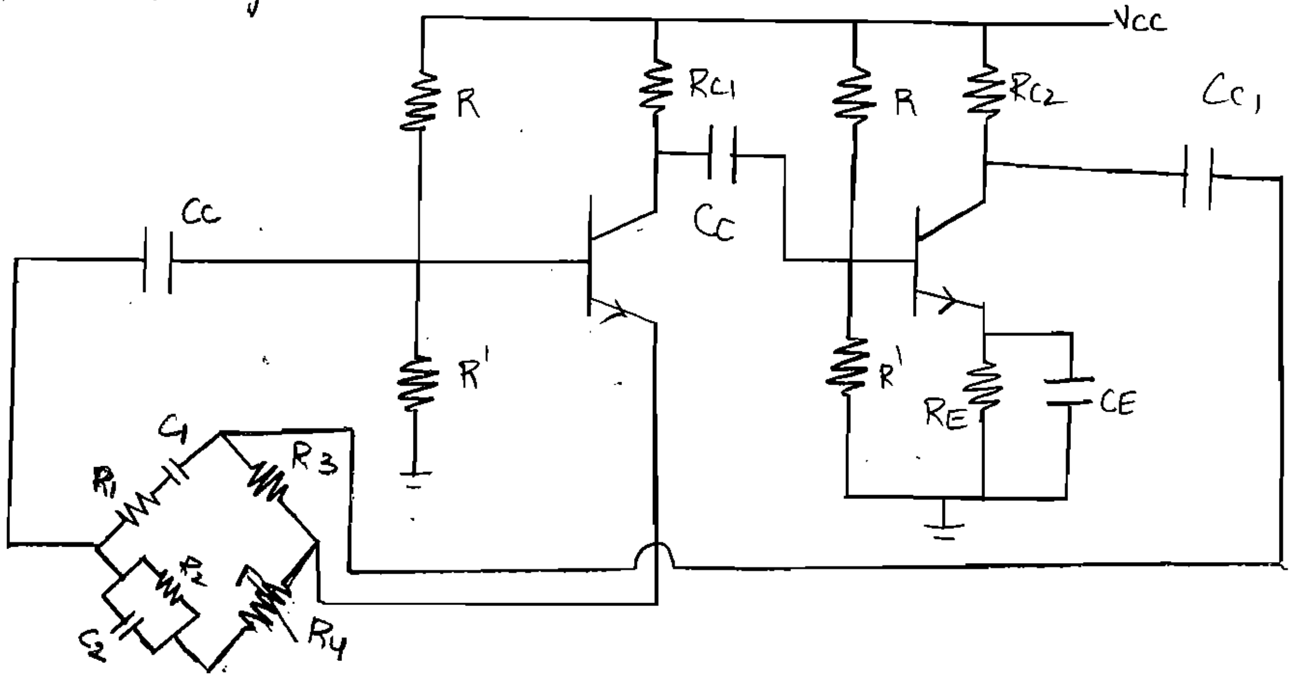
$$k = 2.69$$

$$h_{femin} = 4(2.69) + 23 + \frac{29}{2.69}$$

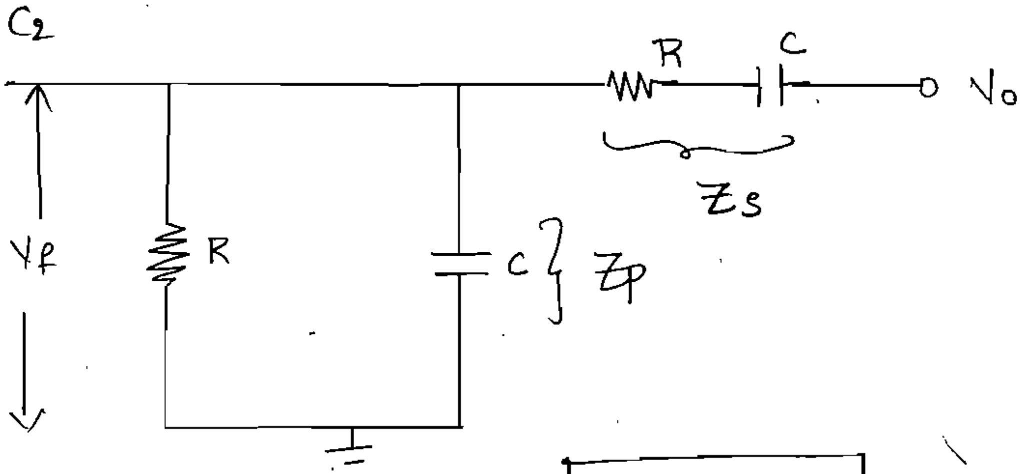
$$= 44.54$$

Wein bridge Oscillator (BJT)

It Consists of two a stage RC Coupled amplifier. Each RC coupled amplifier provides 180° phase shift so that the over all phase shift is 360°. The o/p of the second stage RC coupled amplifier is fedback to the first stage through the bridge network. The bridge network Consists of a feedback circuit called a lead-lag network. The R_1C_1 network from lag portion of the circuit and R_3R_4 network form lead portion of the circuit. At low frequency the lead-lag network acts as a lead network and the phase angle is positive. At Very low frequencies the phase angle is negative and it acts as a lag network. This lead-lag network introduces positive feedback required for oscillation. The resistor R_4 is known as Swamping resistor which introduces negative feedback and input bias stability. The amount of feedback depends on the Voltage divider R_3 and R_4



Considering the bridge network with $R_1 = R_2$ and $C_1 = C_2$



The feedback voltage $\boxed{V_f = \frac{V_o Z_p}{Z_p + Z_s}} \rightarrow (1)$

Where $Z_p = R \parallel X_c$

$$= \frac{R X_c}{R + X_c}$$

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

$$\boxed{Z_p = \frac{R}{1 + j\omega RC}} \rightarrow (2)$$

$$Z_s = R + X_c$$

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

$$\boxed{Z_s = \frac{1 + j\omega RC}{j\omega C}} \rightarrow (3)$$

Substituting Eq's (2), (3) in Eq (1) then, We get

$$V_f = \frac{V_o\left(\frac{R}{1+j\omega RC}\right)}{\left(\frac{1+j\omega RC}{j\omega C}\right)+\left(\frac{R}{1+j\omega RC}\right)}$$

$$= \frac{V_o R j\omega C}{j\omega RC + [1+j\omega RC]^2}$$

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

$$\beta = \frac{V_f}{V_o} = \frac{j\omega RC}{1-\omega^2R^2C^2+j3\omega RC}$$

According to Barkhausen's criteria

$$A\beta = 1$$

$$\frac{Aj\omega RC}{1-\omega^2R^2C^2+j3\omega RC} = 1$$

$$jA\omega RC = 1-\omega^2R^2C^2+j3\omega RC$$

By equating imaginary terms, we get condition for A_V

$$A\omega RC = 3\omega RC$$

$$\boxed{A = 3}$$

By equating real terms, we get frequency of oscillations

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

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

$$\omega^2 = \frac{1}{R^2 C^2}$$

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

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

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

If $R_1 \neq R_2$ and $C_1 \neq C_2$ then, $\boxed{f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}}$

(2) LC Oscillators :-

General form of LC Oscillator :-

The active devices such as BJT, FET and Operational amplifier can be used in the amplifier section. The amplifier produce a phase shift of 180° with a gain Av. The feedback network consisting of reactive elements z_1, z_2 and z_3 produce a phase shift of 180°. This feedback circuit determines the frequency of Oscillation

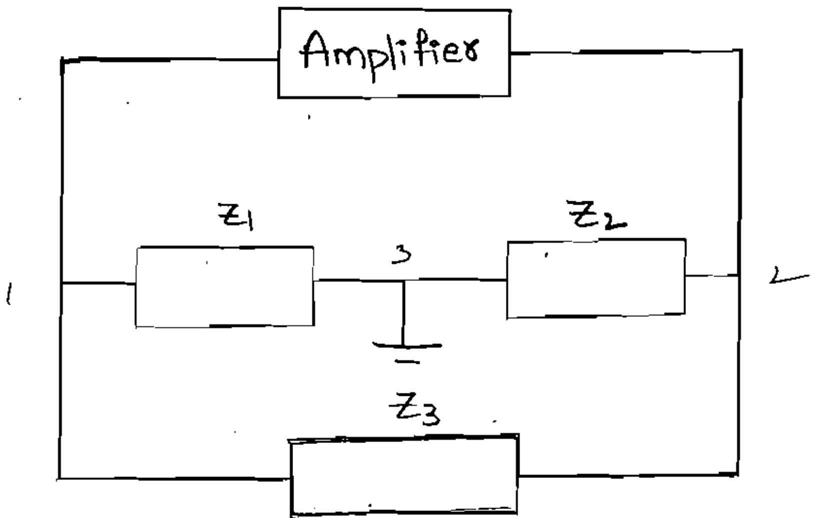
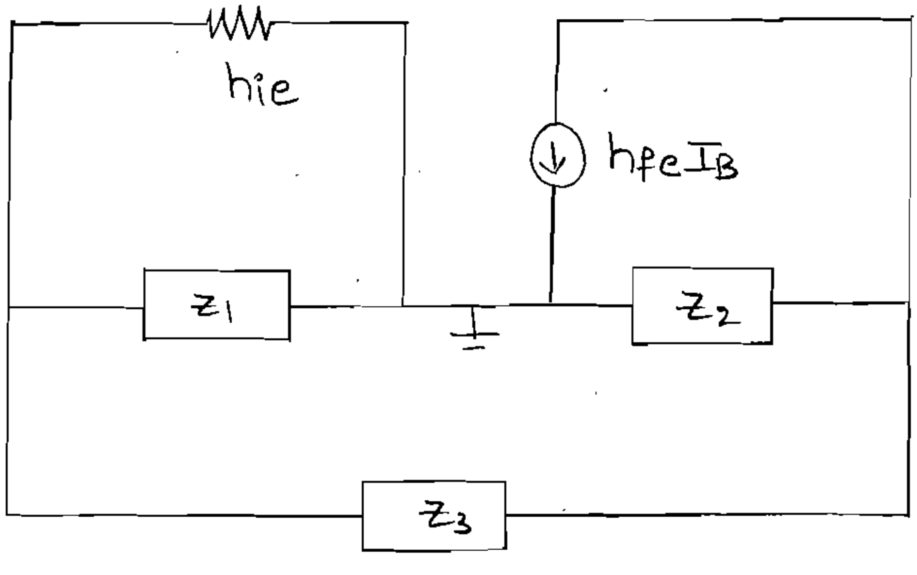
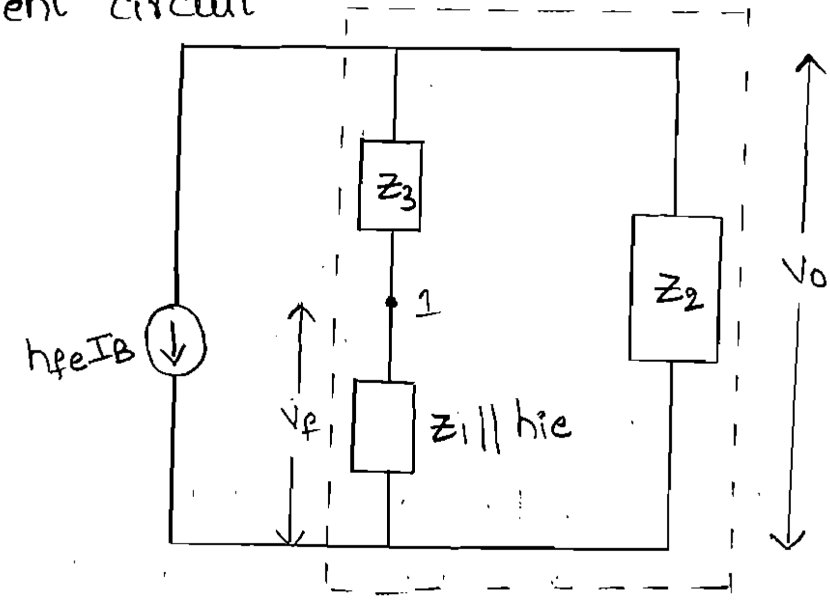


fig: General form of LC oscillator

Replacing amplifier with respect to its h-parameter model



Equivalent circuit



The load impedance $Z_L = (Z_3 + (Z_1 || h_{ie})) || Z_2$

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

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

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

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

The voltage gain of CE amplifier is given by

$$A_V = \frac{-h_{fe} Z_L}{h_{ie}}$$

The feedback voltage $V_f = I_1 (Z_1 || h_{ie})$

$$= I_1 Z_1 h_{ie} / Z_1 + h_{ie}$$

the output voltage $V_0 = I_1[Z_3 + (Z_1 \| h_{ie})]$

$$= I_1\left[Z_3 + \frac{Z_1 h_{ie}}{Z_1 + h_{ie}}\right]$$

$$= I_1\left[\frac{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)}{Z_1 + h_{ie}}\right]$$

the feedback factor $\beta = \frac{V_f}{V_0}$

$$\beta = \frac{\frac{I_1 Z_1 h_{ie}}{Z_1 + h_{ie}}}{\frac{I_1(Z_1 Z_3 + h_{ie}(Z_1 + Z_3))}{Z_1 + h_{ie}}}$$

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

According to Barkhausen's criteria

$$A\beta = 1$$

$$\frac{-h_{fe} Z_L}{\cancel{h_{ie}}} \cdot \frac{Z_1 \cancel{h_{ie}}}{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)} = 1$$

$$\frac{-h_{fe} Z_1}{\cancel{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)}} \cdot \frac{Z_2(\cancel{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)})}{Z_1 Z_2 + Z_1 Z_3 + h_{ie}(Z_1 + Z_2 + Z_3)} = 1$$

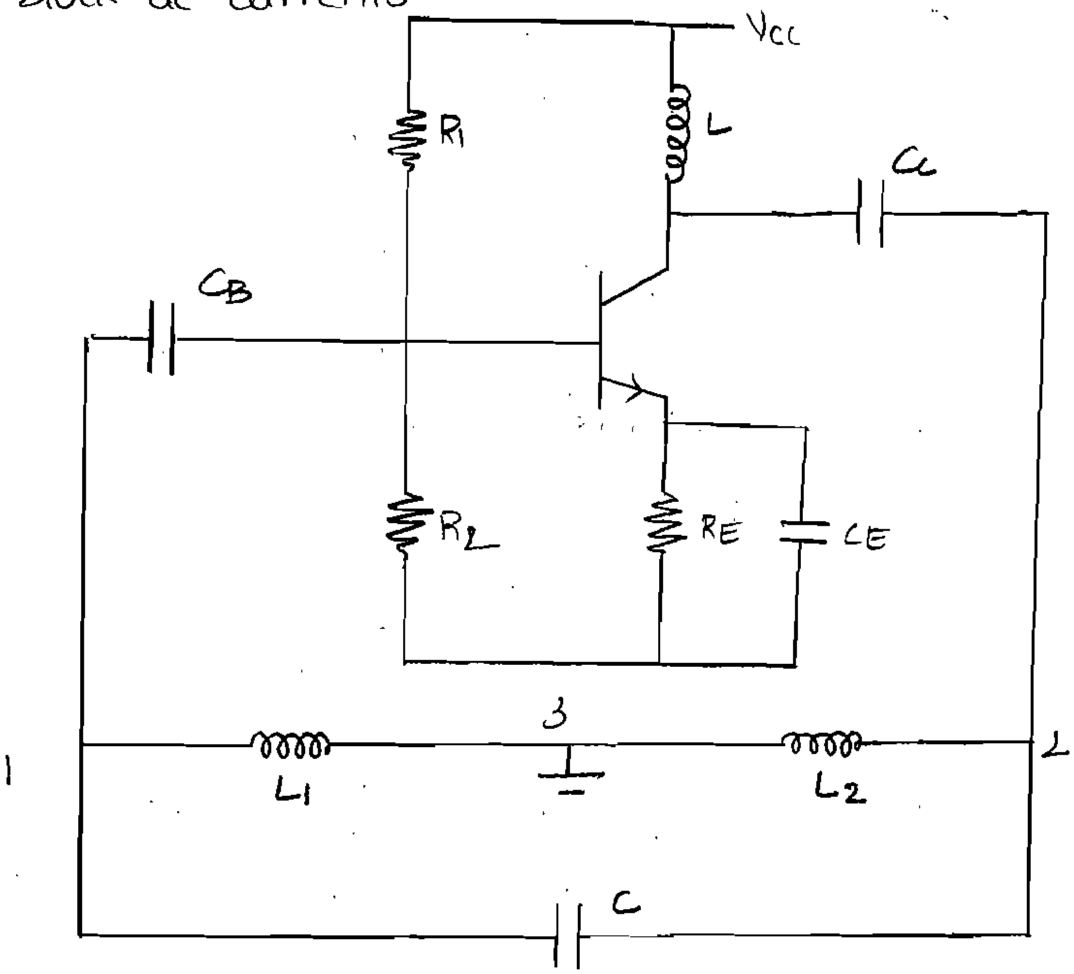
$$-h_{fe} Z_1 Z_2 = Z_1 Z_2 + Z_1 Z_3 + h_{ie}(Z_1 + Z_2 + Z_3)$$

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

The above expression is the general expression of an LC oscillator.

(a) Hartley Oscillator (BJT)

It is a radio frequency Oscillator. It Consists of a tank circuit with two coils L_1 and L_2, and One Capacitor C. The Capacitor C_c is used as Coupling Circuit, permits only ac current to pass to the tank circuit. The Capacitor C_B is known as blocking Capacitor, avoids dc grounding the transistor. A radio frequency choke (L) is connected between power supply V_{cc} and collector. The main function is to allow dc current and to block ac currents.



The general form of an LC Oscillator is

$$[1+h_{fe}]Z_1Z_2 + h_{ie}[Z_1+Z_2+Z_3] + Z_1Z_3 = 0$$

Where $Z_1 = X_{L_1} = j\omega L_1$; $Z_2 = X_{L_2} = j\omega L_2$; $Z_3 = X_C = \frac{1}{j\omega C}$

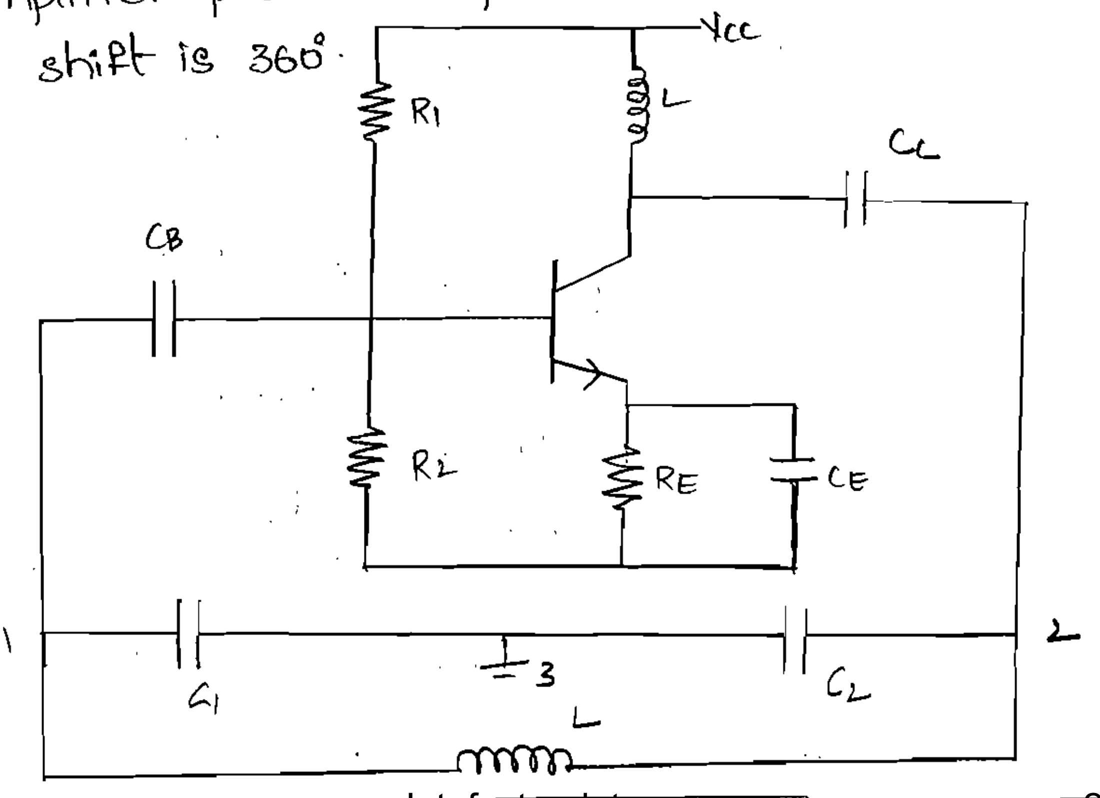
$$\boxed{h_{fe} = \frac{L_1}{L_2}}$$

The above expression is derived without considering the mutual inductance of the inductors L_1 & L_2

If we consider the mutual inductance of the coils then $\boxed{h_{fe} = \frac{L_1+M}{L_2+M}}$

(b) Colpitt's Oscillator (BJT)

The below figure shows the circuit diagram of Colpitt's oscillator. the capacitors C_1 and C_2, inductor L determines the frequency of oscillations. When the supply voltage Vcc is switched on oscillator current is set up in the tank circuit. this current produces ac voltage across C_1 and C_2. The terminal 3 is ground, the voltage across C_2 is 180° out of phase with the voltage across C_1. the phase difference between terminals 1 and 2 is 180°. The CE amplifier provides a phase shift of 180°. Hence total phase shift is 360°.



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

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

By equating imaginary terms we get frequency of Oscillations $h_{ie}\left[\omega L_1 + \omega L_2 - \frac{1}{\omega C}\right] = 0$

$$\omega[L_1 + L_2] = \frac{1}{\omega C}$$

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

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

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

Where $L_{eq} = L_1 + L_2$

By equating real terms we get condition for sustain Oscillations

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

$$\frac{1}{C} = \omega^2 L_2[1+h_{fe}]$$

$$\frac{1}{C} = \frac{1}{(L_1+L_2)C} C_2(1+h_{fe})$$

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

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

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

The General form of LC oscillator is given as

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

Where $Z_1 = \frac{1}{j\omega C_1}$; $Z_2 = \frac{1}{j\omega C_2}$; $Z_3 = j\omega L$

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

$$\frac{-(1+h_{fe})}{\omega^2 C_1C_2} - jh_{ie}\left[\frac{1}{\omega C_1}+\frac{1}{\omega C_2}-\omega L\right] + \frac{L}{L_1} = 0$$

By equating imaginary terms

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

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

$$\omega^2 = \frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)$$

$$= \frac{1}{L}\left(\frac{C_1+C_2}{C_1C_2}\right)$$

$$= \frac{1}{L\left[\frac{C_1C_2}{C_1+C_2}\right]}$$

$$= \frac{1}{LC_{eq}}$$

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

Equating Real terms

$$\frac{-[1+h_{fe}]}{\omega^2 C_1C_2} + \frac{L}{C_1} = 0$$

$$\frac{1+h_{fe}}{\omega^2 C_2} = L$$

$$1+h_{fe} = \omega^2 L C_2$$

$$1+h_{fe} = \frac{1}{L\left[\frac{C_1 C_2}{C_1+C_2}\right]} L C_2$$

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

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

$$h_{fe} = \frac{C_1+C_2}{C_1} - 1$$

$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

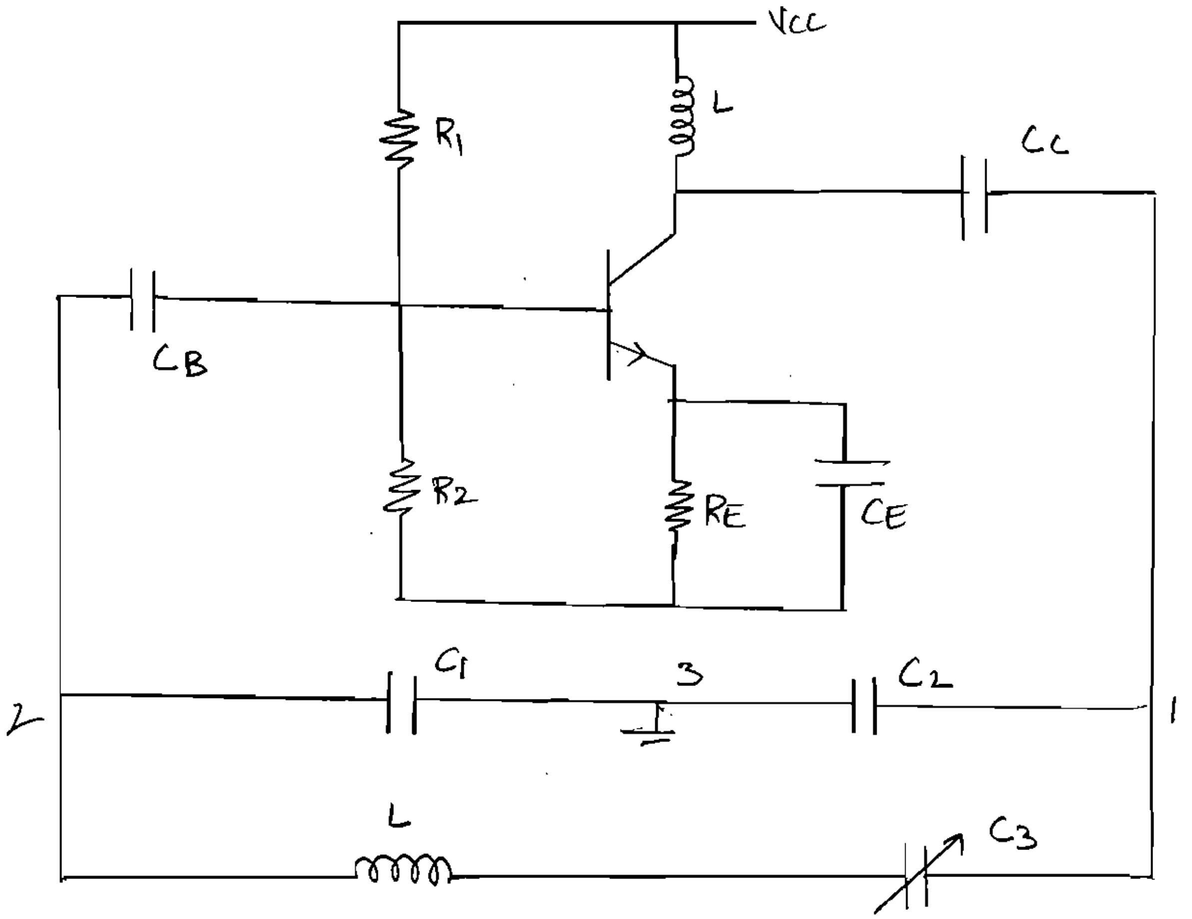
The above Expression is Condition for Sustain Oscillations

(C) Clapp Oscillator :-

It is same as that of Colpitt's Oscillator except that a capacitor C_3 is connected in series with the inductor in the resonant feedback circuit. Since the capacitor C_3 is in series with C_1 and C_2, the same current flows, and the equivalent capacitance is

$$C_{eq} = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}$$

The general form of L-C Oscillator is given as $(1+h_{fe}) Z_1 Z_2 + h_{ie}[Z_1+Z_2+Z_3] + Z_1 Z_3 = 0$



Where $Z_1 = \frac{1}{j\omega C_1}$; $Z_2 = \frac{1}{j\omega C_2}$; $Z_3 = j\omega L + \frac{1}{j\omega C_3}$

$$(1+h_{fe})\left(\frac{1}{j\omega C_1}\right)\left(\frac{1}{j\omega C_2}\right) + h_{ie}\left[\frac{1}{j\omega C_1}+\frac{1}{j\omega C_2}+\left(j\omega L+\frac{1}{j\omega C_3}\right)\right] + \frac{1}{j\omega C_1}\left(j\omega L+\frac{1}{j\omega C_3}\right) = 0.$$

$$\frac{-(1+h_{fe})}{\omega^2 C_1 C_2} - j h_{ie}\left[\frac{1}{\omega C_1}+\frac{1}{\omega C_2}-\omega L+\frac{1}{\omega C_3}\right] + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_3} = 0$$

By equating imaginary terms

$$-h_{ie}\left(\frac{1}{\omega C_1}+\frac{1}{\omega C_2}-\omega L+\frac{1}{\omega C_3}\right) = 0$$

$$\frac{1}{\omega}\left(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}\right) = \omega L$$

$$\omega^2 = \frac{1}{L}\left[\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}\right]$$

But $C_3 << C_1$ and C_3

$$\omega^2 = \frac{1}{LC_3}$$

$$\omega = \frac{1}{\sqrt{LC_3}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{LC_3}}}$$

Equating Real terms

$$\frac{-(1+h_{fe})}{\omega^2 C_1 C_2} + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_2} = 0$$

$$L = \frac{1+h_{fe}}{\omega^2 C_2} + \frac{1}{\omega^2 C_3}$$

$$\omega^2 L = \frac{1+h_{fe}}{C_2} + \frac{1}{C_3}$$

$$\cancel{L} \times \frac{1}{\cancel{L}}\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right] = \frac{1+h_{fe}}{C_2} + \frac{1}{C_3}$$

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

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

$$h_{fe} = \frac{C_1 + C_2}{C_1} - 1$$

$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

~~(d) Crystal Oscillator :-~~

Advantages of Clap Oscillator :-

1. The frequency is stable and accurate
2. The good frequency stability

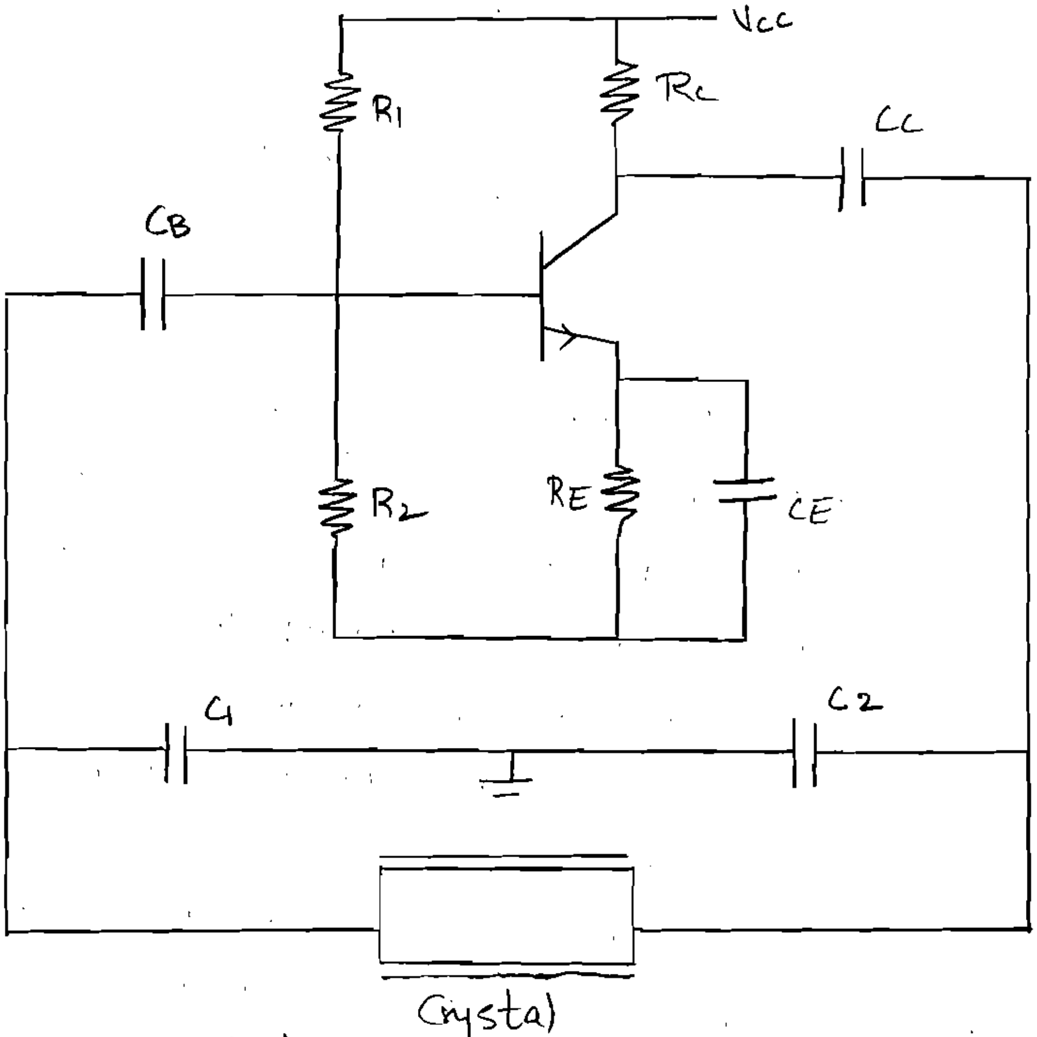
3. The stray Capacitances have no effect on C_3 which decides the frequency.
4. keeping C_3 Variable, frequency can be Varied in desired range.

(d) Crystal Oscillator :-

The Crystals are neither Occurring or synthetically manufactured, exhibiting the piezoelectric field. The piezo-electric effect means under the influence of the mechanical pressure, the Voltage gets generated across the opposite faces of the Crystal. If the mechanical force is applied in such a way to force the Crystal to Vibrate, the ac voltage gets generated across it. Conversely, if the Crystal is subjected to ac voltage, it Vibrates causing mechanical distortion in the Crystal shape. Every Crystal has its own resonating frequency depending on its Cut.

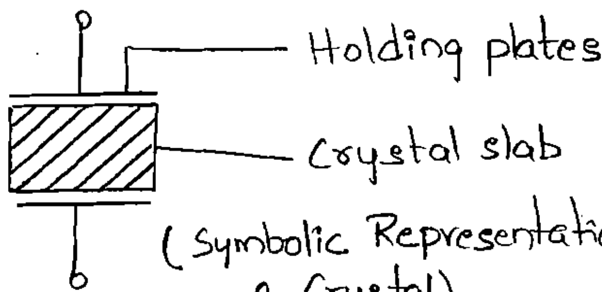
The Crystal has a greater stability in holding the Constant frequency. A Crystal Oscillator is basically a tuned-circuit Oscillator using a piezoelectric Crystal as its resonant tank circuit. The Crystal Oscillators are preferred when greater frequency stability is required. Hence the Crystals are used in watches, communication transmitters and receivers etc

The main Substances exhibiting the piezoelectric effect are quartz, Rochelle salt and tourmaline. Rochelle salt have the greatest piezoelectric ~~of~~ activity. Tourmaline is most expensive and hence used rarely in practice. Quartz is inexpensive and easily available and hence Commonly used in Crystals.



Constructional Details :-

The nature shape of a quartz Crystal is a hexagonal prism
But for its practical use, it is cut to the rectangular
slab. This slab is then mounted between the two metal plates
the metal plates are called holding plates, as they hold
the Crystal slab in between them.



(Symbolic Representation of a Crystal)

A.C. Equivalent Circuit :-

When the Crystal is not vibrating, it is equivalent to a Capacitance due to the mechanical mounting of the Crystal.

Such a Capacitance existing due to the two metal plates separated by a dielectric like Crystal slab, is called mounting Capacitance denoted by C_M or C.

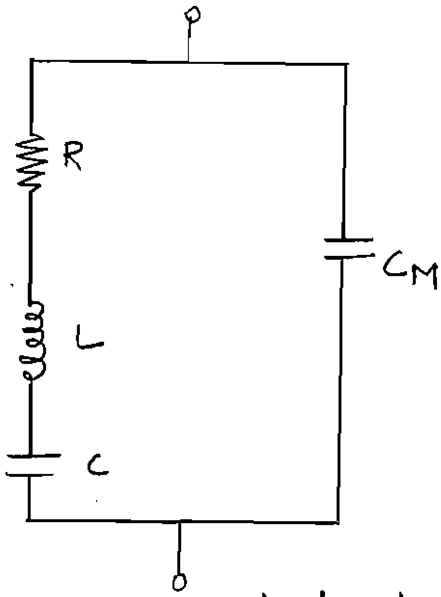


fig: A.C Equivalent ckt of a Crystal

When it is vibrating, there are internal frictional losses which are denoted by a resistance R. While the mass of the Crystal, which is indication of its inertia is represented by an inductance L. In vibrating condition, it is having some stiffness, which is represented by Capacitor C.

The resonant frequency of the Crystal is given as

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{Q^2}{1+Q^2}}}$$

Where Q is the Quality factor of an RLC ckt

$$\boxed{Q = \frac{\omega L}{R}}$$

Generally the Value of Q is above 20,000

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

The frequency of the Crystal also depends upon its thickness $\boxed{f_r \propto \frac{1}{t}}$

As the thickness of the Crystal there may be a chance for the Crystal to get damaged. Hence practically Crystal oscillators are used ~~used~~ to develop the frequencies upto 200 or 300 KHz only.

Series and parallel Resonance :-

The Crystal has two resonating frequency, Series resonant frequency and parallel resonant frequency. The Series frequency is obtained when the reactance of the Series RLC leg is equal i.e., $X_L = X_C$. Generally the Series frequency is equal to the resonant frequency

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

The parallel frequency is obtained when reactance of series elements is equal to reactance of CM (Mounted Capacitance)

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

$$\text{Where } C_{eq} = \frac{CC_M}{C+C_M}$$

Colpitts Oscillator (FET) :-

If in the basic circuit of Colpitts Oscillator, the FET is used as an active device in the amplifier stage, the circuit is called as FET colpitts Oscillator. The tank circuit remains same as before. The Working of the circuit and oscillating frequency also remains the same.

The practical circuit of FET Colpitt's Oscillator is shown in below figure.

(The derivation of Colpitts Oscillator FET is Same as the Colpitts Oscillator using BJT)

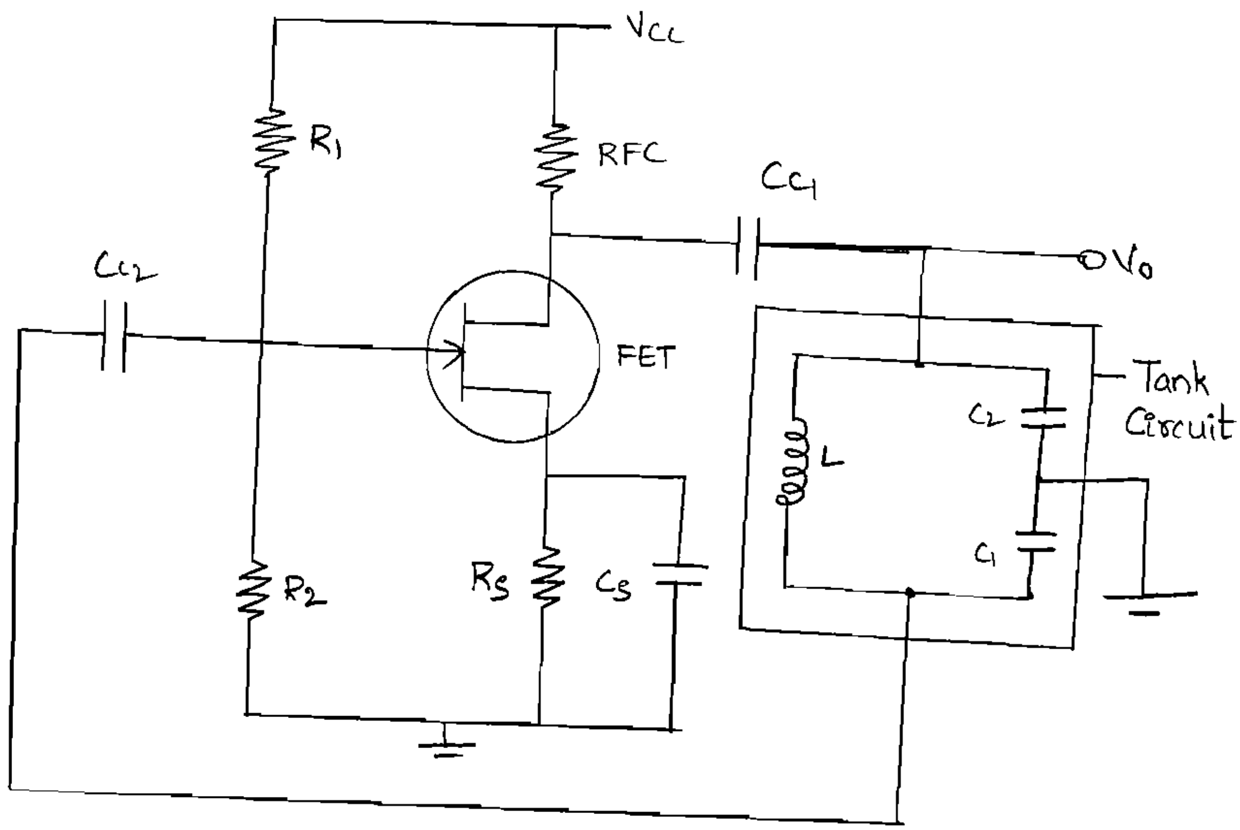


fig: FET colpitts Oscillator

The Oscillating frequency $f = \frac{1}{2\pi\sqrt{LC_{eq}}}$

Where $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$

FET Hartley Oscillator :-

If FET is used as an active device in an amplifier stage, then the circuit is called FET Hartley Oscillator.

The Resistances R_1, R_2 bias the FET along with R_s. the C_s in the Source bypass Capacitor. To maintain Q point stable, Coupling capacitors C_{c1}, C_{c2} are used. These have very large values Compared to capacitor C.

We know, $X_1 + X_2 + X_3 = 0$

$X_1 = j\omega L_1$, $X_2 = j\omega L_2$, $X_3 = \frac{1}{j\omega C}$

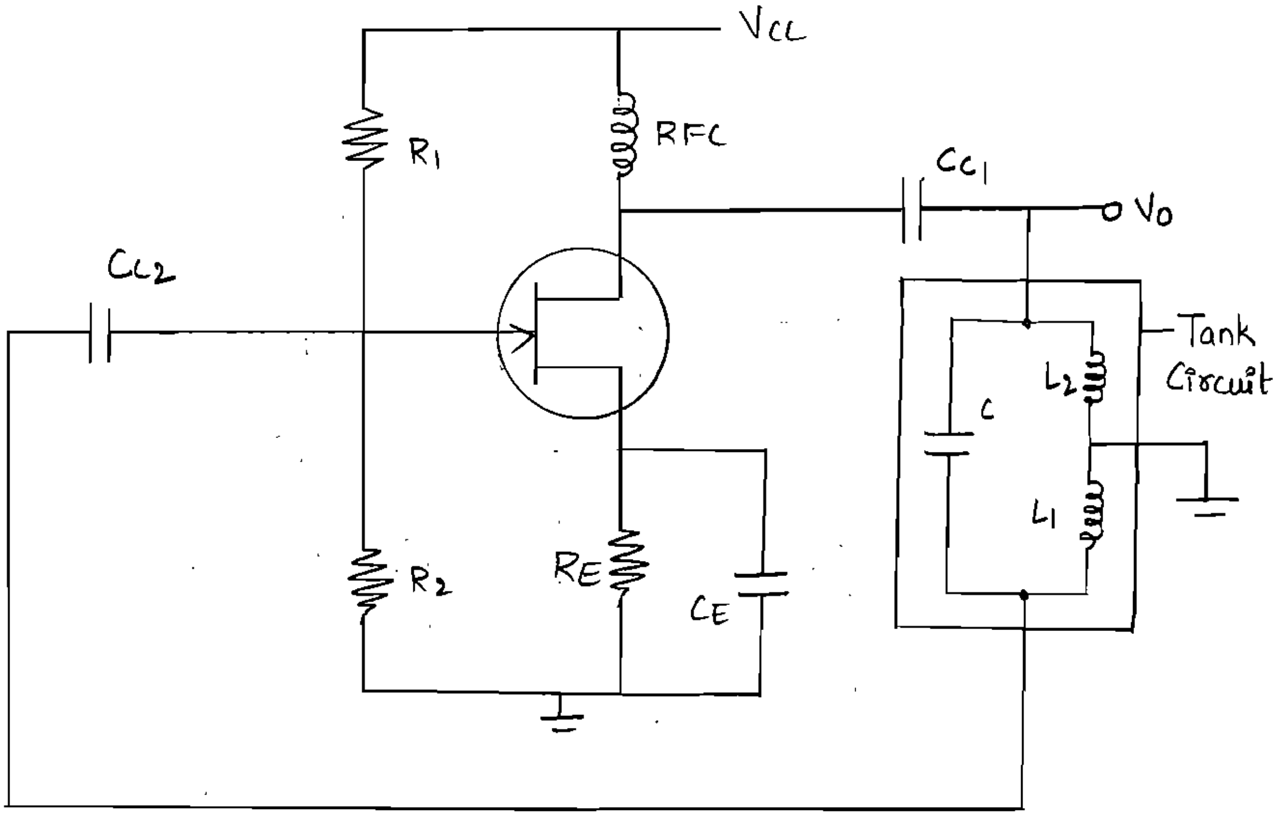


fig: FET Hartley oscillator

We get the same expression $f = \frac{1}{2\pi\sqrt{C L_{eq}}}$

Where $L_{eq} = L_1 + L_2$ or $L_1 + L_2 + 2M$

this is dependent on whether L_1, L_2 are wound on the same core or not. If $L_1 = L_2 = L$, then the freq. of oscillations is given by

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

Amplitude Stabilization in Oscillators :-

The oscillator output amplitude if not stabilized, attains the extreme levels of saturation i.e., $\pm V_{sat}$. But this can cause the distortion in the output waveform. Hence it is necessary to minimize the distortion and reduce the output amplitude within the acceptable range.

the circuit used in the oscillator for this purpose is called oscillator amplitude stabilization circuit. It makes the oscillations damped and ensures that are not sustained if amplitude increases beyond a particular value.

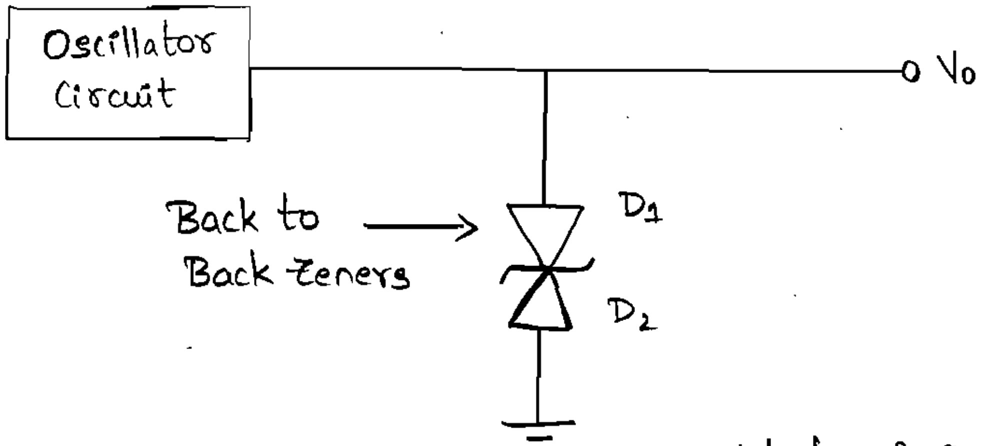


fig: 4.1 limiting output amplitude of oscillator

One simple way of limiting the oscillator output amplitude is to provide back to back zener diodes connected at the output terminals. This is shown in fig: 4.1 the voltage across back to back zeners remains constant and limits the value of output amplitude. the output amplitude can be set by selecting proper zener diodes.

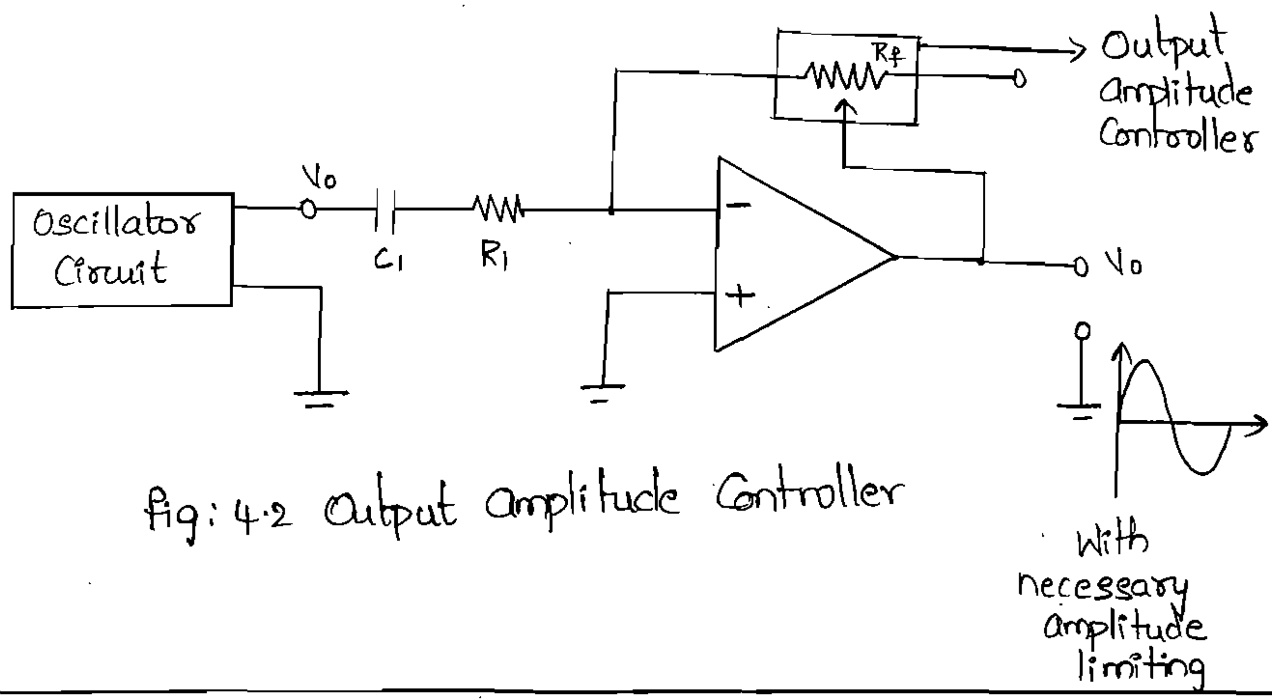


fig: 4.2 Output amplitude Controller

The Output amplitude adjustment can also be achieved by an operational amplifier circuit with variable feedback resistor as shown in fig: 4.2

The gain of the o/p-amplitude circuit is $\left|\frac{R_f}{R_1}\right|$. Thus when $R_f = R_1$ the output amplitude remains same as oscillator output except phase reversal. By controlling the value of R_f properly, the output amplitude can be controlled as per the need.

Frequency ~~Oscillator~~ stability of an Oscillator :-

The Oscillator circuit does not maintain the stable frequency for a long period. When a circuit maintain a stable frequency of oscillation, then we say that the circuit has frequency stability.

The drawback of transistor Oscillator circuit is that they do not maintain frequency stability during a long time of operation. The change in oscillation frequency in such circuits may arise due to the following factors.

1. Tolerance of Components :-

All Components used to construct an Oscillator have tolerances, therefore the Oscillating frequency may vary 10% higher or lower than the desired frequency.

2. Temperature :-

The Component values change with the variation in temperature and this causes change in Oscillator frequency.

3. Operating point :-

The selection of operating point in non-linear region affects the frequency stability of the Oscillator.

4. Power Supply Variation :-

Due to Variation in the power supply applied to the active device, there may be shift in frequency of oscillation.

5. Load Resistance :-

A change in output load may change the effective resistance of the tank circuit there by Causing change in Oscillator output frequency.

6. Capacitance Variation :-

Any change in interelement Capacitance and stray Capacitance affect the frequency stability of Oscillation.

The Crystal Oscillator is an Oscillator which produce stable frequency Oscillations.