2.3 WIEN BRIDGE OSCILLATOR

- It uses a non-inverting amplifier (does not provide any phase shift during amplifier stage).
- As total phase shift required is 0^0 or $2n\pi$ radians, in wien bridge type no phase shift is necessary through feedback.
- Thus the total phase shift around a loop is 0^0.
- A Wien-Bridge Oscillator is a type of phase-shift oscillator which is based upon a Wien-Bridge network comprising of four arms connected in a bridge fashion.
- Here two arms are purely resistive while the other two arms are a combination of resistors and capacitors.
- In particular, one arm has resistor and capacitor connected in series (R_1 and C_1) while the other has them in parallel (R_2 and C_2).
- Two arms of the bridge R_1 , C_1 in series and R_2 , C_2 in parallel are frequency sensitive.
- In this circuit, at high frequencies, the reactance of the capacitors C_1 and C_2 will be much less due to which the voltage V_0 will become zero as R_2 will be shorted.
- At low frequencies, the reactance of the capacitors C_1 and C_2 will become very high. However even in this case, the output voltage V_0 will remain at zero only, as the capacitor C_1 would be acting as an open circuit.
- This kind of behavior exhibited by the Wien-Bridge network makes it a lead-lag circuit in the case of low and high frequencies, respectively

Transistorised wien bridge oscillator:

- In this circuit two stage common emitter transistor amplifiers is used.
- Each stage contributes 180^0 phase shift hence the total phase shift due to the amplifier stage becomes 360^0 which is necessary as per the oscillator conditions.
- The bridge consists of R and C in series, R and C in parallel, R_3 and R_4.
- The feedback is applied from the collector of Q_2 through the coupling capacitor, to the bridge circuit.
- The two stage amplifier provides a gain much more than 3 and it is necessary to reduce it.

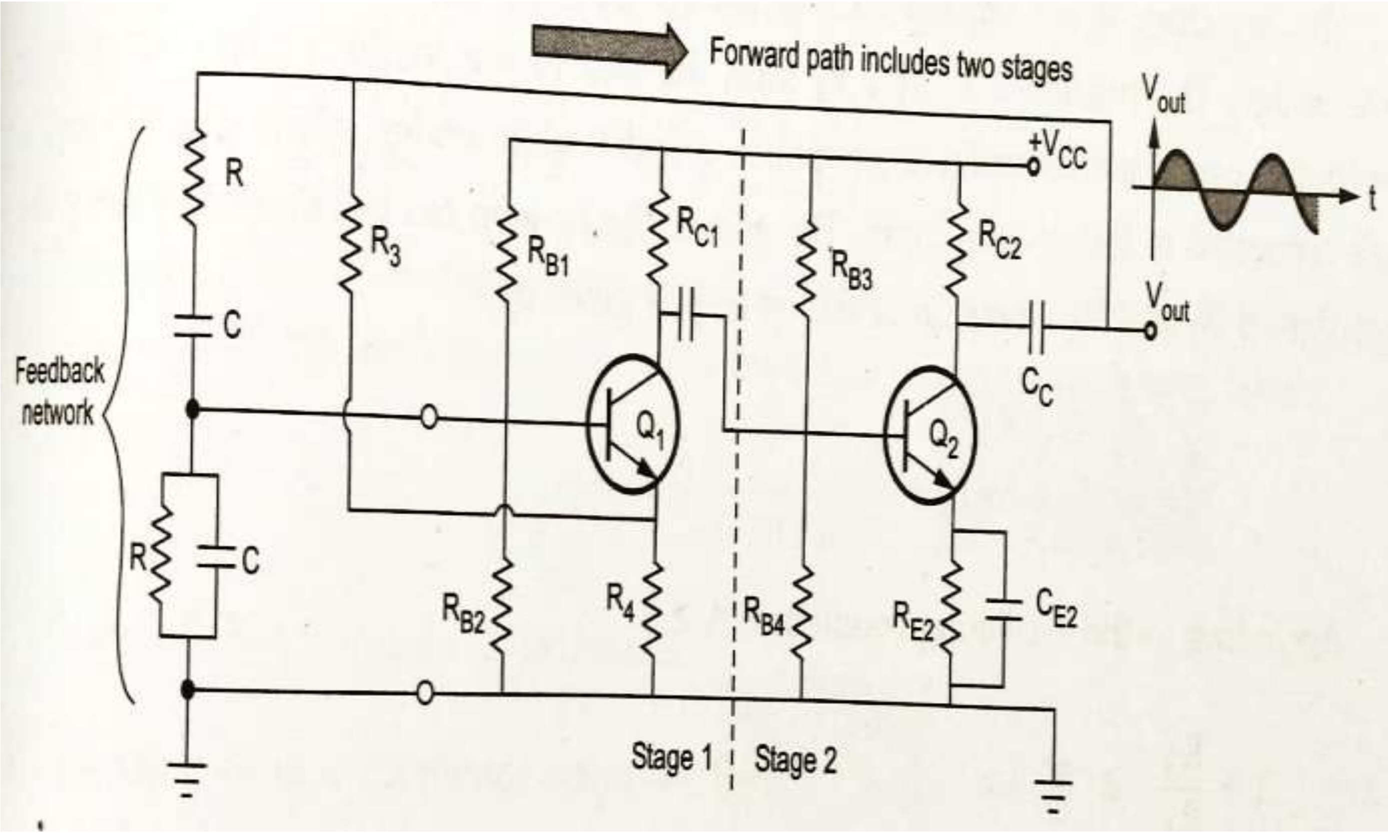
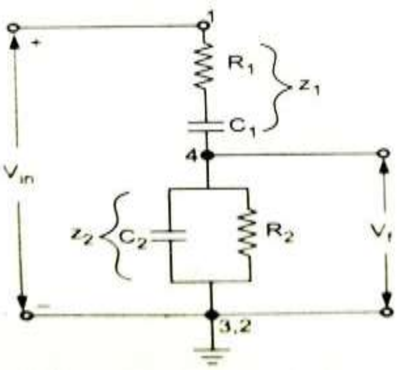


Figure: 2.3.1 wien bridge oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-388]

- To reduce the gain, the negative feedback is used without bypassing the resistance R_4.
- The amplitude stability can be improved using a nonlinear resistor for R_4.
- Increase in the amplitude of the oscillations, increases the current through nonlinear resistance, which results into an increase in the value of non linear resistance R_4.

Derivation of wien bridge oscillator



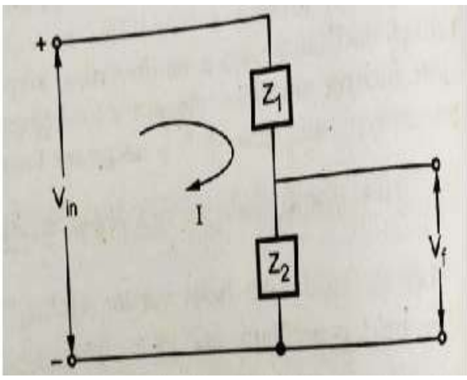


Figure: 2.3.2 feedback network of wien bridge oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-389]

- From figure 2.3.2

$$Z_1 = R_1 + \frac{1}{j\omega C_1} = \frac{1 + j\omega R_1 C_1}{j\omega C_1}$$

$$Z_2 = R_2 || \frac{1}{j\omega C_2} = \frac{R_2}{1 + j\omega R_2 C_2}$$

Replaing jω = s,

$$Z_1 = \frac{1 + sR_1C_1}{sC_1}$$

$$Z_2 = \frac{R_2}{1 + sR_2C_2}$$

$$I = \frac{V_{in}}{Z_1 + Z_2}$$

And $V_f = IZ_2$

$$V_f = \frac{V_{in}Z_2}{Z_1 + Z_2}$$

$$\beta = \frac{V_f}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

- Substituting the value of Z_1 and Z_2

$$\beta = \frac{\frac{R_2}{1+sR_2C_2}}{\frac{1+sR_1C_1}{sC_1} + \frac{R_2}{1+sR_2C_2}}$$

- Replacing s by jω, $s^2 = -\omega^2$ and rationalizing simplifying the expression

$$\beta = \frac{\omega^2 C_1 R_2 (R_1C_1 + R_2C_2 + C_1R_2) + j\omega C_1 R_2 (1 - \omega^2 R_1R_2C_1C_2)}{(1 - \omega^2 R_1R_2C_1C_2)^2 + \omega^2 (R_1C_1 + R_2C_2 + C_1R_2)^2}$$

- To have zero phase shift of the feedback network, its imaginary part must be zero

$$\omega C_1 R_2 (1 - \omega^2 R_1R_2C_1C_2) = 0$$

$$\omega^2 = \frac{1}{R_1R_2C_1C_2}$$

$$\omega = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

$$f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

- This is the frequency of the oscillator and it shows that the components of the frequency sensitive arms are the deciding factors for the frequency.
- In practice $R_1=R_2=R$ and $C_1=C_2=C$

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

$$\beta = \frac{1}{3}$$

- The positive sign of β indicates that the phase shift by the feedback network is 0^0

$$|A\beta| \geq 1$$

$$|A| \geq \frac{1}{|\beta|} \geq \frac{1}{\frac{1}{3}}$$

$$|A| \geq 3$$

- This the required gain of the amplifier stage without any phase shift.
- If $R_1 \neq R_2$ and $C_1 \neq C_2$ then

$$f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

$$\beta = \frac{C_1R_2}{R_1C_1 + R_2C_2 + C_1R_2}$$

$$A \geq \frac{R_1C_1 + R_2C_2 + C_1R_2}{C_1R_2}$$

Advantages:

1. Mounting the two capacitors on common shaft and varying their values, the frequency can be varied as per the requirement.
2. The stability high
3. The frequency range can be selected simply by using decade resistance box
4. High gain

2.1 BARKHAUSEN CRITERION FOR OSCILLATION

Introduction:

- An oscillator is a circuit which basically acts as generator, generating the output signal which oscillates with constant amplitude and constant desired frequency.
- 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 feedback to the amplifier as its input, is in phase with the voltage gain A is shown in figure 2.1.1

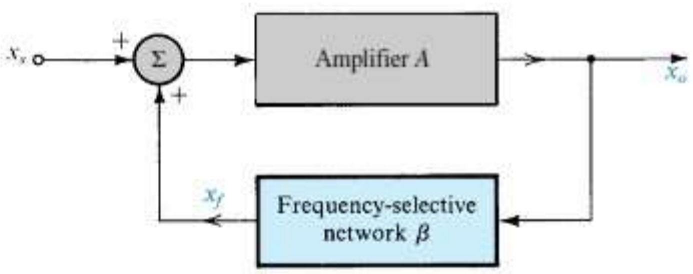


Figure 2.1.1 the basic structure of a sinusoidal oscillator

[Source: microelectronic circuits by sedra & smith, page no: 1337]

- Assume that a sinusoidal input signal 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 fed back to the input with the help of a feedback netork.no phase Change is introduced by the feedback network.
- As the phase of the feedback signal is same as that of the input applied the feedback is called positive feedback.
- The closed loop gain of positive feedback is given by,

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

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

Barkhausen criterion

It states that

1. The total phase shift around a loop as the signal proceeds from input through amplifier, feedback network back to the input again, completing a loop, is precisely 0^0 or 360^0 or of course an integral multiply of 2π radians.
2. The magnitude of the product of the open loop gain of the amplifier (A) and the feedback factor $\beta$is unity i.e. $|A\beta|=1$

- If satisfying these conditions, the circuit works as an oscillator producing sustained oscillations of constant frequency and amplitude.
- In reality no input is needed to start the oscillation. In practice $A\beta>1$ to start the oscillation and then circuit adjust itself to get $A\beta=1$, finally resulting into self-sustained oscillations.
- Let us see the effect of the magnitude of the product $A\beta$ on the nature of the oscillations.

1. $|A\beta| >1$

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

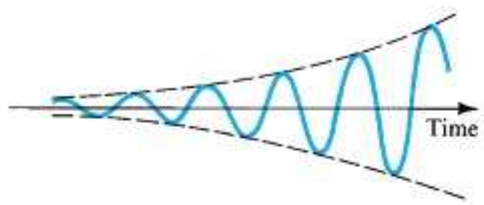


Figure 2.1.2 the growing type oscillation

[Source: microelectronic circuits by sedra & smith, page no: 871]

2. $|A\beta| >1$

When the total phase shift around a loop is 00 or 3600 and $|A\beta| = 1$, then the oscillations are with constant frequency amplitude called sustained oscillations.

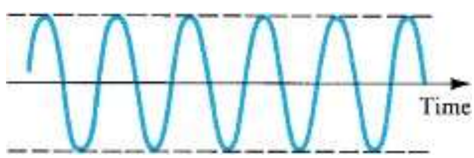


Figure 2.1.3 Sustained oscillation

[Source: microelectronic circuits by sedra & smith, page no: 871]

3. |Aβ| >1

When the total phase shift around a loop is 00 or 3600 and |Aβ| >1, then the oscillations are of decaying type i.e such oscillation amplitude decreases exponentially and the oscillations finally cease.

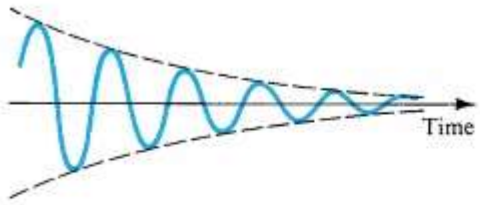


Figure 2.1.4 exponentially decaying oscillation

[Source: microelectronic circuits by sedra & smith, page no: 871]

Starting voltage:

- It is mentioned that no external input is required in case of oscillators.
- Every resistance has some free electrons. Under the influence of normal room temperature, these free electrons move randomly in various directions. Such movements of the free electrons generate a voltage called noise voltage, across the resistance.
- Such noise voltages present across the resistances are amplified. Hence to amplify such small noise voltage and start the oscillations, |Aβ| is kept greater than unity at start.
- The circuit adjusts itself to get |Aβ| =1 and with phase shift of 360^0 we get sustained oscillations.

2.5 CLAPP OSCILLATOR

- To achieve the frequency stability, Clapp oscillator circuit is slightly modified in practice, called clap oscillator.
- The basic tank circuit with two capacitive reactance and one inductive reactance is same, but the modification in the tank circuit is that one more capacitor C_3 is introduced in series with the inductance.
- The transistorized clapp oscillator is shown in fig 2.6.1

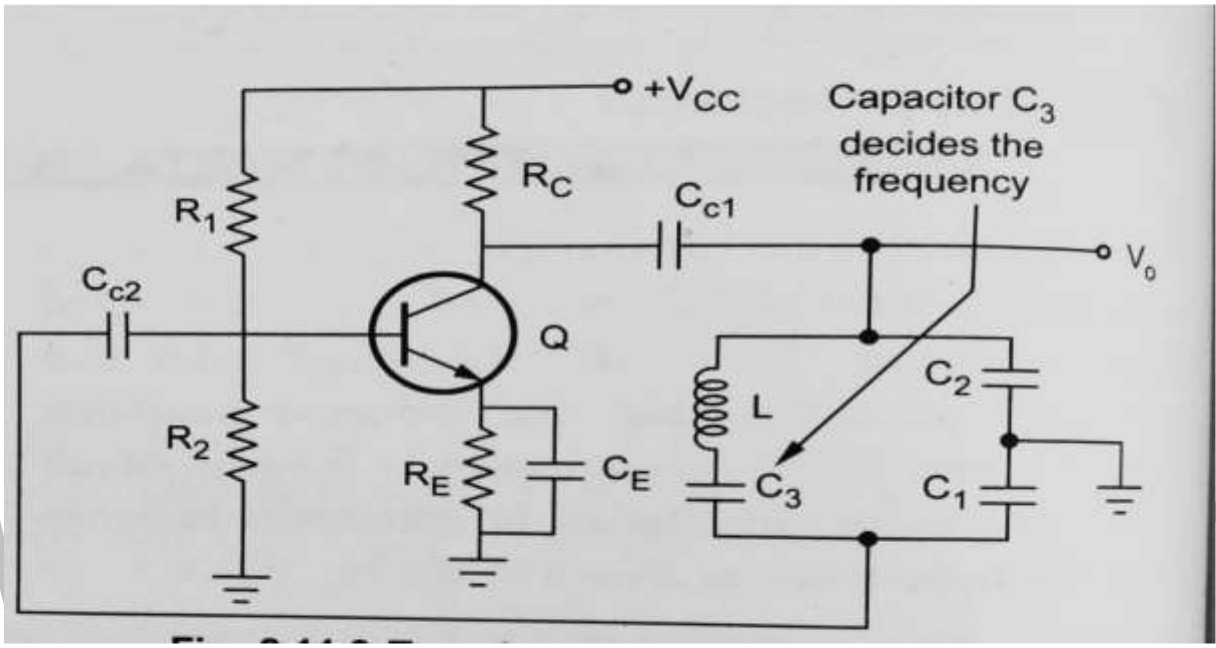


Figure 2.6.1 Clapp oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-406]

- The frequency of the clap oscillator is stable and accurate
- The transistor and stray capacitances have no effect on C_3 hence good freueny stability is achieved.
- C_3 is that it can be kept variable.as frequency depends on C_3.

Derivation of frequency of oscillation:

- The output current I_c which is h_{fe} , I_b acts as input to the feedback network.
- While the base current I_b acts as the output current of tank circuit, following through the input impedance of the amplifier h_{ie}.
- The equivalent circuit shown in fig 2.6.2

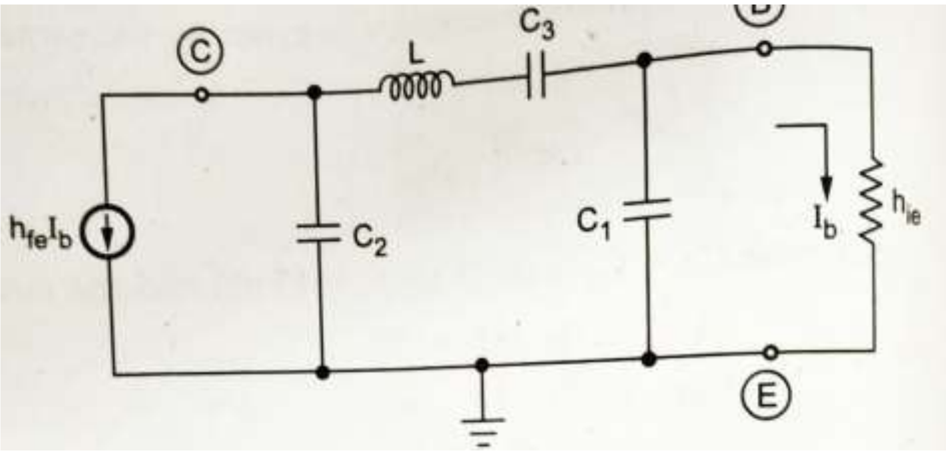


Figure 2.6.2 Clapp oscillator equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-407]

- Converting the current source into voltage source as shown in fig 2.6.3

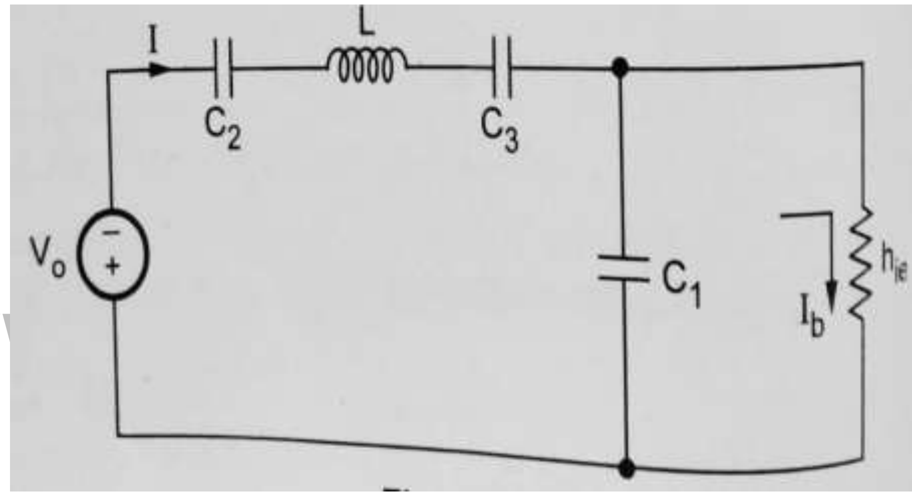


Figure 2.6.3 modified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-407

$$V_0 = h_{fe}I_bX_{C2} = h_{fe}I_b\frac{1}{j\omega C_2} = \frac{h_{fe}I_b}{j\omega C_2} ------(1)$$

- The total current I drawn from the supply.

$$I = \frac{-V_o}{[X_{C2} + X_{C3} + X_L] + [X_{C1}||h_{ie}]} ------(2)$$

- Negative sign, as current direction shown in opposite to the polarities of V_o.

$$X_{C2} + X_{C3} + X_L = \frac{1}{j\omega C_2} + j\omega L + \frac{1}{j\omega C_3}$$

$$X_{C1}||h_{ie} = \frac{\frac{1}{j\omega C_1}h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}$$

Substituting in the equation (2) we get,

$$I = \frac{-\left[\frac{h_{fe} I_b}{j\omega C_2}\right]}{\left[\frac{1}{j\omega C_2} + j\omega L + \frac{1}{j\omega C_3}\right] + \left[\frac{\frac{1}{j\omega C_1} h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}\right]} - - - (3)$$

Replacing jω by s

$$I = \frac{-\left[\frac{h_{fe} I_b}{sC_2}\right]}{\left[\frac{1}{sC_2} + sL + \frac{1}{sC_3}\right] + \left[\frac{\frac{1}{sC_1} h_{ie}}{\frac{1}{sC_1} + h_{ie}}\right]} - - - (4)$$

Simplifying above equation we get

$$I = \frac{-h_{fe} I_b C_3 (1 + sC_1 h_{ie})}{s^3 LC_1C_2C_3 h_{ie} + s^2 LC_2C_3 + sh_{ie}[C_2C_3 + C_1C_2 + C_1C_3] + C_2 + C_3} - -(5)$$

According to current division in parallel circuit,

$$I_b = I\,X\,\frac{X_{C1}}{X_{C1} + h_{ie}} = I\,X\,\frac{\frac{1}{j\omega C_1}}{h_{ie} + \frac{1}{j\omega C_1}} = \frac{I}{(1 + S\,C_1 h_{ie})} - - - - - - (6)$$

Substituting in the equation (5) we get,

$$I_b = \frac{\frac{-h_{fe} I_b C_3 (1 + sC_1 h_{ie})}{s^3 LC_1C_2C_3 h_{ie} + s^2 LC_2C_3 + sh_{ie}[C_2C_3 + C_1C_2 + C_1C_3] + C_2 + C_3}}{(1 + S\,C_1 h_{ie})}$$

$$1 = \frac{-h_{fe} C_3}{s^3 LC_1C_2C_3 h_{ie} + s^2 LC_2C_3 + sh_{ie}[C_2C_3 + C_1C_2 + C_1C_3] + C_2 + C_3}$$

Substtuting s=jω, $s^2 = j^2\,\omega^2$; $s^3 = -j\,\omega^3$

$$1 = \frac{-h_{fe} C_3}{C_2 + C_3 - \omega^2 LC_2C_3 + j\omega h_{ie}\{[C_2C_3 + C_1C_2 + C_1C_3] - \omega^2 LC_1C_2C_3\}}$$

There is no need to Rationalizing this as there are no j terms in the numerator

To satisfy this equation, imaginary part of R.H.S must be zero.

$$[C_2C_3 + C_1C_2 + C_1C_3] - \omega^2 LC_1C_2C_3 = 0$$

$$\omega^2 = \frac{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}{L}$$

$$\omega = \sqrt{\frac{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}{L}}$$

$$f = \frac{\sqrt{\frac{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}}{L}}}{2\pi}$$

Simply

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

Where

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

But as $C_3 << C_1$ and C_2, $C_{eq} = C_3$

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

This is the required frequency of oscillations for the clap oscillator.

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2.5 COLPITTS OSCILLATOR

- An LC oscillator which uses two capacitive reactance and one inductive reactance in the feedback network is called Colpitts oscillator
- The transistorized Colpitts oscillator is shown in fig 2.5.1

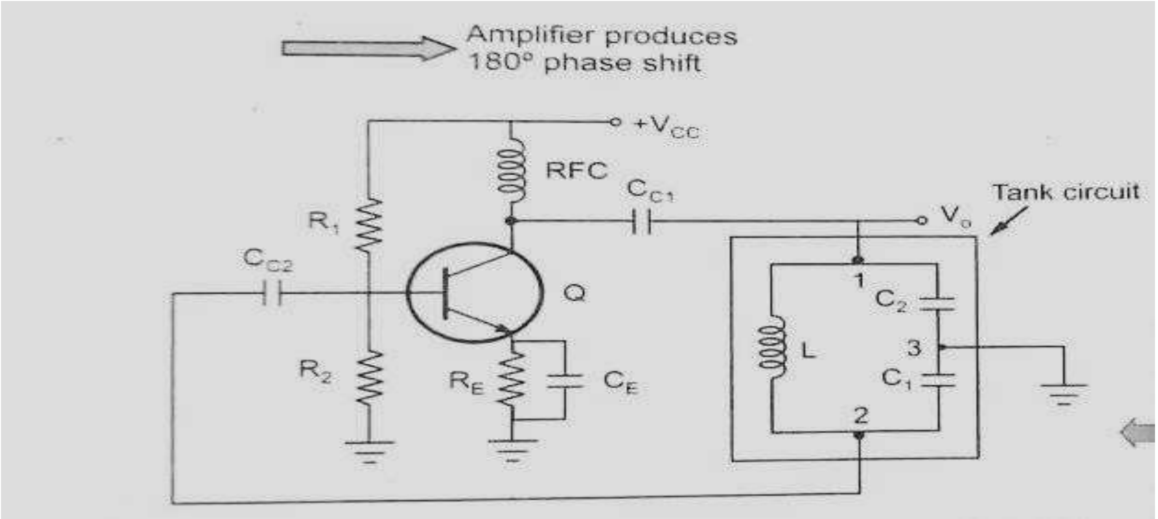


Figure 2.5.1 Colpitts oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-401]

- The basic circuit is same as transisoried Hartley oscillator, except the tank circuit.
- The common emitter amplifier causes a phase shift of 180^0, while the tank circuit adds further 180^0 phase shift, to satisfy oscillating conditions.

Derivation of frequency of oscillation:

- The output current I_c which is h_{fe} , I_b acts as input to the feedback network.
- While the base current I_b acts as the output current of tank circuit, following through the input impedance of the amplifier h_{ie}.
- The equivalent circuit shown in fig 2.5.2

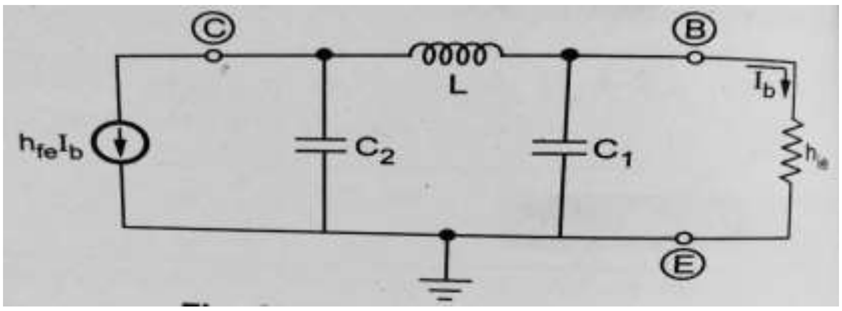


Figure 2.5.2 Colpitts oscillator equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-402]

- Converting the current source into voltage source as shown in fig 2.5.3

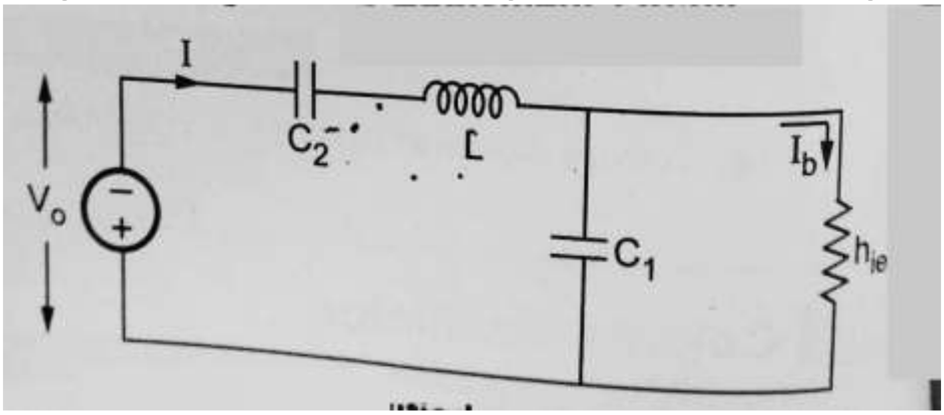


Figure 2.5.3 modified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-401]

$$V_0 = h_{fe} I_b X_{C2} = h_{fe} I_b \frac{1}{j\omega C_2} = \frac{-j h_{fe} I_b}{\omega C_2} ------(1)$$

- the total current I drawn from the supply.

$$I = \frac{-V_o}{[X_{C2} + X_L] + [X_{C1} || h_{ie}]} ------(2)$$

- Negative sign, as current direction shown in opposite to the polarities of V_o.

$$X_{C2} + X_L = j\omega L + \frac{1}{j\omega C_2} = \frac{-j(1-\omega^2 L C_2)}{\omega C_2}$$

$$X_{C1} || h_{ie} = \frac{-j h_{ie}}{-j + \omega C_1 h_{ie}}$$

Substituting in the equation (2) we get,

$$I = \frac{-\left[\frac{-j h_{fe} I_b}{\omega C_2}\right]}{\left[\frac{-j(1-\omega^2 L C_2)}{\omega C_2}\right] + \left[\frac{-j h_{ie}}{-j+\omega C_1 h_{ie}}\right]} ---(3)$$

According to current division in parallel circuit,

$$I_b = I\,X\,\frac{X_{C1}}{X_{C1} + h_{ie}} = I\,X\,\frac{\frac{1}{j\omega C_1}}{h_{ie} + \frac{1}{j\omega C_1}} = \frac{-jI}{-j + \omega\, C_1 h_{ie}} ------(4)$$

Substituting in the equation (3) we get,

$$I_b = \frac{-j\,\frac{-\left[\frac{-j h_{fe} I_b}{\omega C_2}\right]}{\left[\frac{-j(1-\omega^2 L C_2)}{\omega C_2}\right] + \left[\frac{-j h_{ie}}{-j+\omega C_1 h_{ie}}\right]}}{-j + \omega\, C_1 h_{ie}} --(5)$$

$$1 = \frac{h_{fe}}{(1-\omega^2 LC_2) + j\omega h_{ie}[C_1 + C_2 - \omega^2 C_2 C_1 L)} --(6)$$

There is no need to Rationalizing this as there are no j terms in the numerator

To satisfy this equation, imaginary part of R.H.S must be zero.

$$\omega h_{ie}[C_1 + C_2 - \omega^2 C_2 C_1 L) = 0$$

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

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

$$f = \frac{1}{2\pi\sqrt{L(\frac{C_1 C_2}{C_1 + C_2})}}$$

This is the frequency of the oscillations.

At this frequency, the restriction of the value of h_{fe} can be obtained, by equating the magnitudes of the both sides of the equation

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

1.5 HARTLEY OSCILLATOR

LC oscillator:

- The oscillators which use the elements L and C to produce the oscillations are called LC oscillators.
- The circuit using elements L and C is called tank circuit or oscillatory circuit, which is an important part of LC oscillators.
- These oscillators are used for high frequency range from 00 kHz up to few GHz.
- The LC tank circuit consists of elements L and C connected in parallel

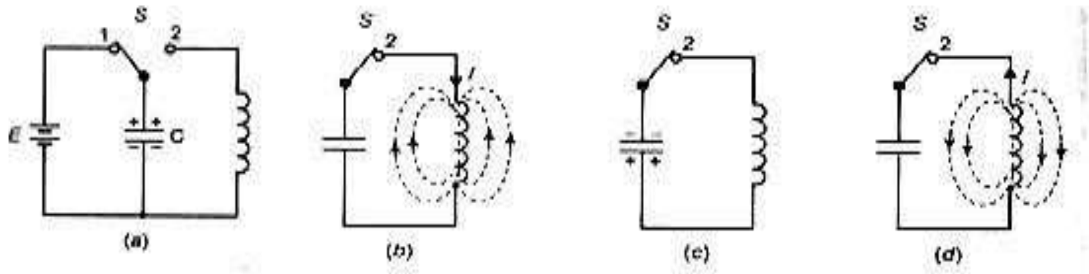


Figure 2.4.1 Operation of LC tank circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-395]

- The energy keeps oscillating between electric potential energy and magnetic field energy
- The capacitor stores energy in the form of an electrostatic field and which produces a potential (static voltage) across its plates, while the inductive coil stores its energy in the form of an electromagnetic field.
- The capacitor is charged up to the DC supply voltage, V by putting the switch in position 1.
- When the capacitor is fully charged the switch changes to position 2.
- The charged capacitor is now connected in parallel across the inductive coil so the capacitor begins to discharge itself through the coil.
- The voltage across C starts falling as the current through the coil begins to rise. This rising current sets up an electromagnetic field around the coil which resists this flow of current.
- When the capacitor, C is completely discharged the energy that was

originally stored in the capacitor, C as an electrostatic filed is now stored in the inductive coil, L as an electromagneticfield around the coils windings.

- As there is now no external voltage in the circuit to maintain the current within the coil, it starts to fall as the electromagnetic field begins to collapse. A back emf is induced in the coil (e=-Ldi/dt) keeping the current flowing in the original direction. This current now charges up the capacitor, c with the opposite polarity to its original charge.
- Capacitor continues to charge up until the current reduces to zero and the electromagnetic field ofthe coil has collapsed completely.
- The capacitor now starts to discharge again back through the coil and the whole process so repeated.
- The polarity of the voltage changes as the energy is passed back and forth between the capacitor and inductor producing an AC type sinusoidal voltage and current waveform.
- The frequency of oscillations generated by LC tank circuit depends on the values L and C is given by,

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

Hartley Oscillator:

- A LC oscillator which uses two inductive reactance and one capacitive reactance in its feedback network is called Hartley oscillator.

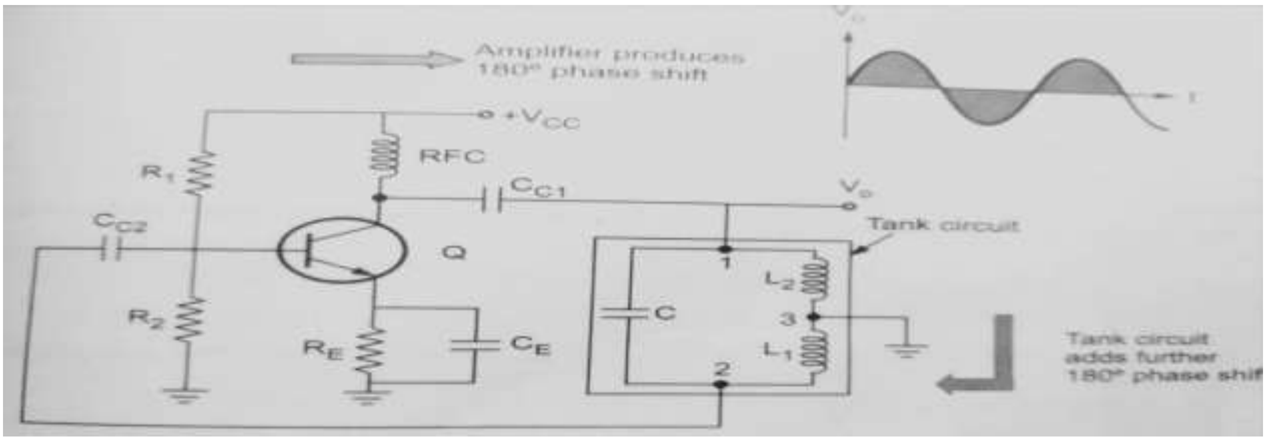


Figure 2.4.2 Hartley oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

- CE amplifier provides a phase shift of 180^0 and LC feedback network provides additional 180^0 phase shift.
- The resistance R1 and R2 are the biasing resistances. The RFC is the radio frequency choke.
- Its reactance value is very high frequencies; hence it can be treated as open circuit. While for d.c conditions, the reactance is zero hence cause no problem for d.c capacitors.
- Hence due to RFC, the isolation between a.c. and d.c operation is achieved.

Derivation of frequency of oscillations:

- Output current is collector current is

$$h_{fe} I_b$$

- As h_{ie} is the input impedance of the transistor. The output of the feedback is current I_b which is the input current of the transistor.

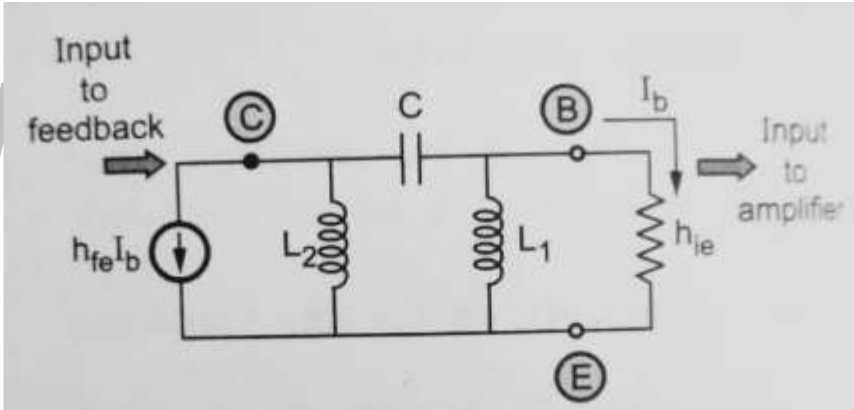


Figure 2.4.3 equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

- While input to the feedback network is the output of the transistor which is $I_c = h_{fe} I_b$, converting current source into voltage source

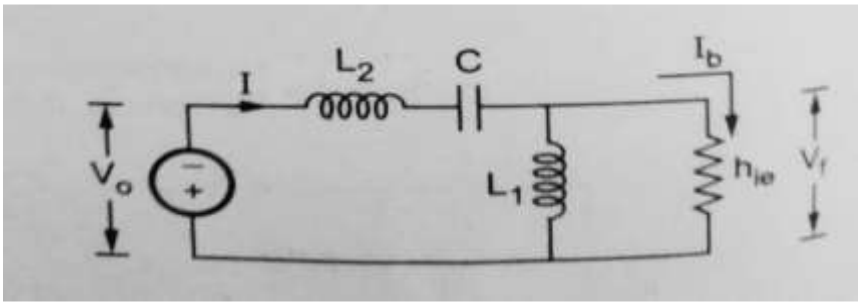


Figure 2.4.4 simplified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

$$V_0 = h_{fe} I_b X_{L2} = h_{fe} I_b j\omega L_2 ------(1)$$

- Now L_1 and h_{ie} are in parallel, so the total current I drawn from the supply.

$$I = \frac{-V_o}{[X_{L2} + X_c] + [X_{L1} || h_{ie}]} ------(2)$$

- Negative sign, as current direction shown in opposite to the polarities of V_o.

$$X_{L2} + X_c = j\omega L_2 + \frac{1}{j\omega C}$$

$$X_{L1} || h_{ie} = \frac{j\omega L_1 h_{ie}}{(j\omega L_1 + h_{ie})}$$

Substituting in the equation (2) we get,

$$I = \frac{-h_{fe} I_b j\omega L_2}{\left[j\omega L_2 + \frac{1}{j\omega C}\right] + [\frac{j\omega L_1 h_{ie}}{(j\omega L_1 + h_{ie})}]} ---(3)$$

According to current division in parallel circuit,

$$I_b = I\ X\ \frac{X_{L1}}{X_{L1} + h_{ie}} = I\ X \frac{j\omega L_1}{j\omega L_1 + h_{ie}} ------(4)$$

Substituting in the equation (3) we get,

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

$$1 = \frac{j\omega^3\ h_{fe} C\ L_1 L_2}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)] + j\omega L_1(1 - \omega^2 L_2 C)}$$

Rationalizing R.H.S of the above equation.

$$1 = \frac{\omega^4 h_{fe} L_1^2 L_2 C(1 - \omega^2 L_2 C) + j\omega^3\ h_{fe} C\ L_1 L_2[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]^2 + \omega^2 L_1^2(1 - \omega^2 L_2 C)^2} --(5)$$

To satisfy this equation, imaginary part of R.H.S must be zero.

$$\omega^3\ h_{fe} C\ L_1 L_2[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)] = 0$$

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

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

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

This is the frequency of the oscillations.

- At this frequency, the restriction of the value of h_{fe} can be obtained, by equating the magnitudes of the both sides of the equation (5)

$$1 = \frac{\omega^4 h_{fe} L_1^2 L_2 C(1-\omega^2 L_2 C)}{0+\omega^2 L_1^2 (1-\omega^2 L_2 C)^2}$$

At

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

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

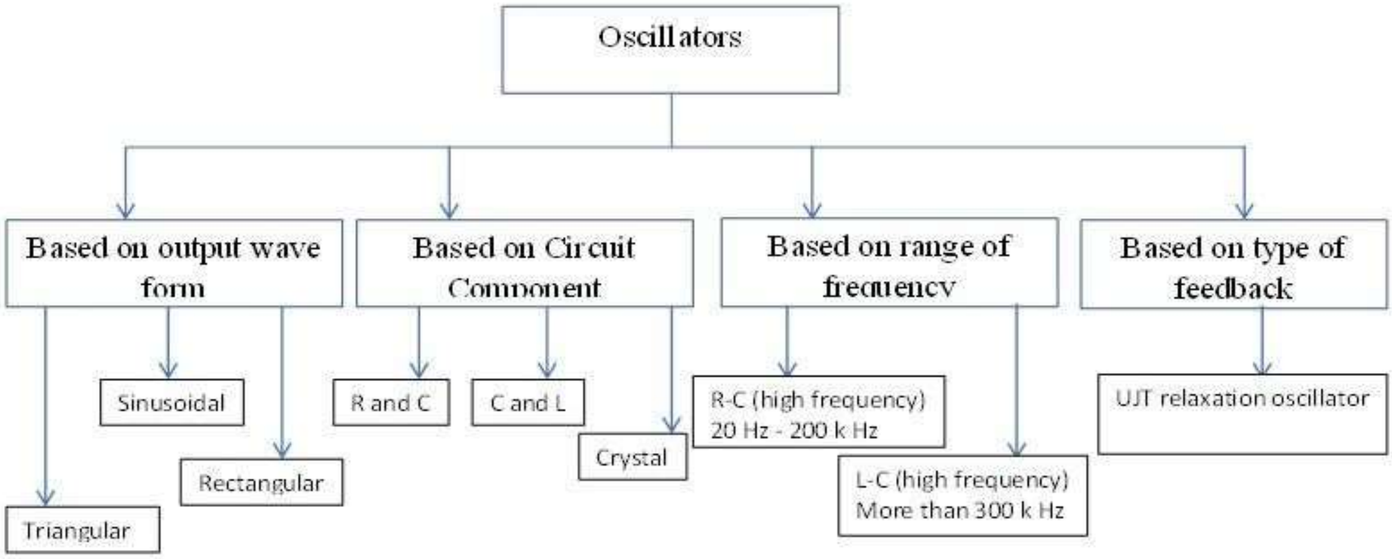
This value of h_{fe} required to satisfy the oscillating conditions.

For mutual inductance of M

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

1.5 PHASE SHIFT OSCILLATOR

Classification of oscillator:



R-C Phase shift Oscillator:

- RC phase shift oscillator basically consists of an amplifier and a feedback network consisting of resistor and capacitors arranged in ladder fashion. Hence such an oscillator is also called ladder type RC phase shift oscillator.
- RC network is used in feedback path. In oscillator, feedback network must introduce a phase shift of 180^0 to obtain total phase shift around a loop as 360^0
- Thus if one RC network produces phase shift of $\varphi=60^0$ then to produce phase shift of 180^0 such three RC networks must be connected in cascade.
- Hence in RC phase shift oscillator, the feedback network consists of three RC sections each producing a phase shift of 60^0, thus total phase shift due to feedback is 180^0.
- Transistorized RC phase shift oscillator, a transistor is used as an active device element of the amplifier.

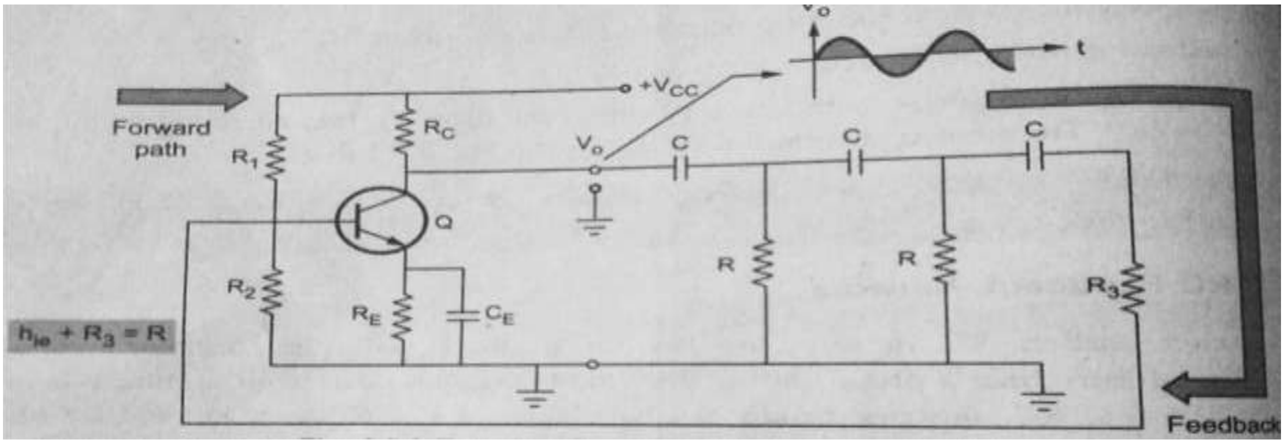


Figure: 2.2.1 RC phase shift oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

- Fig 2.2.1 shows a practical transistorized RC phase shift oscillator which uses a common emitter single stage amplifier and a phase shifting network consisting of three identical RC sections.
- The output of the feedback network gets loaded due to the low input impedance of a transistor. Hence an emitter follower input stage before the common emitter amplifier stage can be used, to avoid the problem of low input impedance.
- But if only single stage is to be used then the voltage shunt feedback, denoted by resistance R_3 in the figure 2.2.1 is used, connected in series with the amplifier input resistance.
- A phase shifting network is a feedback network, so output of the amplifier is given as an input to the feedback network.
- While the output of the feedback network is given as an input to the amplifier. Thus amplifier supplies its own input, through the feedback network.
- Neglecting R_1 and R_2 as these are sufficiently large,

  h_{ie}=input impedance of the amplifier stage

$$h_{ie}+R_3 = R$$

- This ensures that all the three sections of the phase shifting network are identical.

Derivation for the frequency of oscillations:

- Replacing the transistor by its approximate h-parameter model, we get the equivalent circuit as shown in the fig 2.2.2

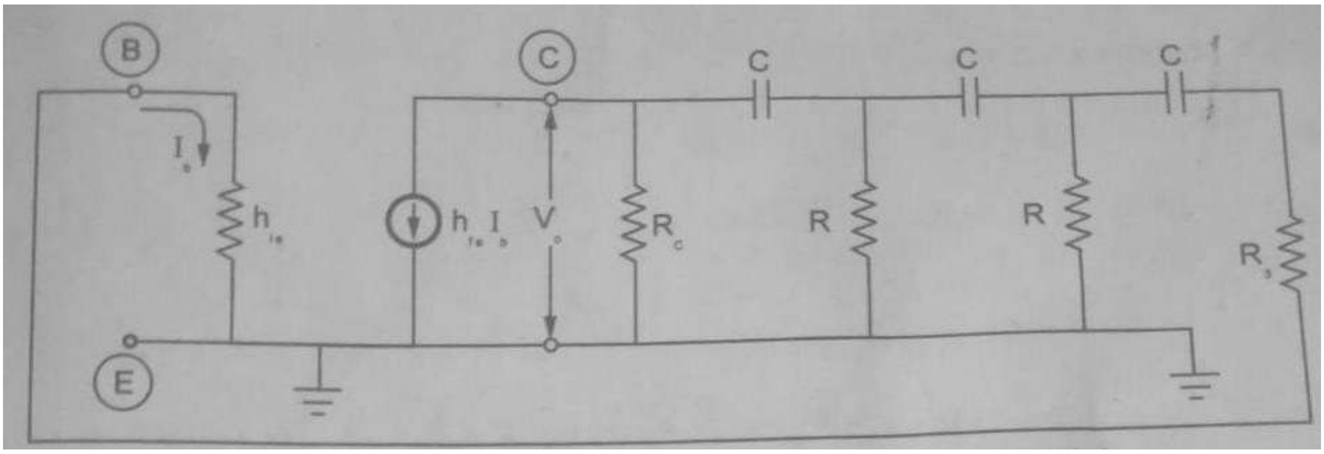


Figure: 2.2.2 RC phase shift oscillator-equivalent circuit using h-parameter

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

We can replace

$$h_{ie} + R_3 = R$$

And the current source h_{fe} I_b by its equivalent voltage source

Assume k=─ ▁

- The modified equivalent circuit is shown in fig 2.2.3

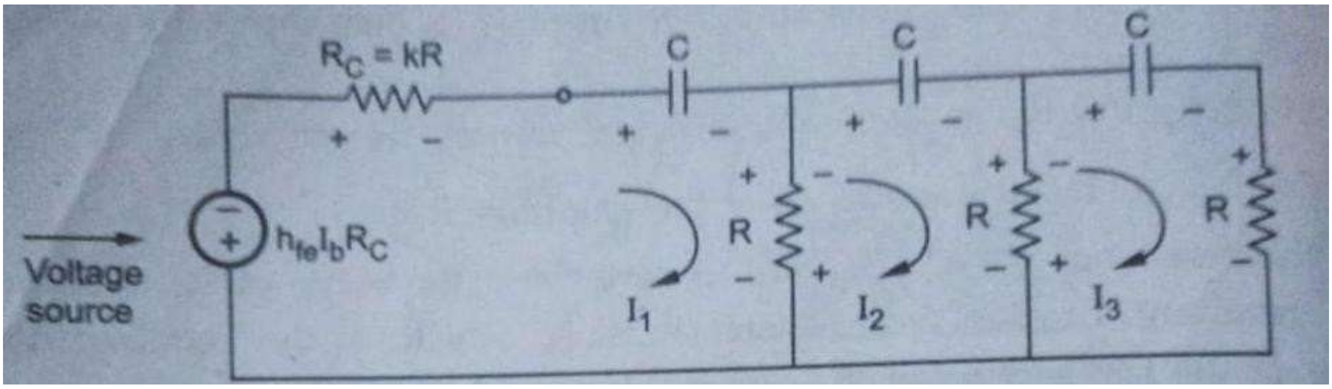


Figure: 2.2.3 RC phase shift oscillator-modified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

- Applying KVL for the various loops in the modified equivalent circuit we get,

For loop 1,

$$-I_1 R_c - \frac{1}{j\omega C} I_1 - I_1 R + I_2 R - h_{fe} I_b R_c = 0$$

Replacing R_c by kR and jω by s

$$+I_1\left[(k+1)R+\frac{1}{sC}\right]-I_2R=-h_{fe}I_bkR--------(1)$$

For loop 2,

$$-I_1R+I_2\left[2R+\frac{1}{sC}\right]-I_3R=0--------(2)$$

For loop 3,

$$-I_2R+I_3\left[2R+\frac{1}{sC}\right]=0--------(3)$$

Using Cramer's rule to solve for I_3,

$$D=\begin{vmatrix}(k+1)R+\frac{1}{sC} & -R & 0\\ -R & 2R+\frac{1}{sC} & -R\\ 0 & -R & 2R+\frac{1}{sC}\end{vmatrix}$$

$$D=\frac{s^3C^3R^3[3k+1]+s^2C^2R^2[4k+6]+sRC[5+k]+1}{s^3C^3}----(4)$$

Now D_3,

$$D_3=\begin{vmatrix}(k+1)R+\frac{1}{sC} & -R & h_{fe}I_bkR\\ -R & 2R+\frac{1}{sC} & 0\\ 0 & -R & 0\end{vmatrix}$$

$$D_3=-kR^3h_{fe}I_b------(5)$$

$$I_3=\frac{D_3}{D}$$

$$I_3=\frac{-kR^3h_{fe}I_bs^3C^3}{s^3C^3R^3[3k+1]+s^2C^2R^2[4k+6]+sRC[5+k]+1}----(5)$$

$$I_3=output\ current\ of\ the\ feedback\ circuit$$

$$I_b = input\ current\ of\ the\ amplifier$$

$$I_c = h_{fe}I_b = input\ current\ of\ the\ feedback\ circuit.$$

$$\beta = \frac{output\ of\ feedback\ circuit}{input\ to\ feedback\ circuit} = \frac{I_3}{h_{fe}I_b}$$

And

$$A = \frac{output\ of amplifier\ circuit}{input\ to\ amplifier\ circuit} = \frac{I_c}{I_b} = h_{fe}$$

$$A\beta = \frac{I_3}{I_b} - - - - - - - - (6)$$

Using equation (6) we get

$$A\beta = \frac{-kR^3h_{fe}s^3C^3}{s^3C^3R^3[3k+1] + s^2C^2R^2[4k+6] + sRC[5+k] + 1} - - - (7)$$

Substituting s=jω, $s^2 = -\omega^2$, $s^3 = -j\omega^3$ in equation (7) and separating real and imaginary part in the denominator we get,

$$A\beta = \frac{+kR^3h_{fe}j\omega^3C^3}{[1 - 4k\omega^2C^2R^2 - 6\omega^2C^2R^2] - j\omega[3k\omega^2R^3C^3 + \omega^2R^3C^3 - 5RC - kRC]}$$

Dividing numerator and denominator by $j\omega^3C^3R^3$,

$$A\beta = \frac{+kh_{fe}}{\left[\frac{1-4k\omega^2C^2R^2-6\omega^2C^2R^2}{j\omega^3C^3R^3}\right] - \left\{\frac{j\omega[3k\omega^2R^3C^3+\omega^2R^3C^3-5RC-kRC]}{j\omega^3C^3R^3}\right\}}$$

Replacing -1/ j = j and replacing $\frac{1}{\omega RC} = \alpha$ for simplicity

$$A\beta = \frac{kh_{fe}}{[-3k - 1 + 5\alpha^2 + k\alpha^2] - j[\alpha^3 - 4k\alpha - 6\alpha]} - - - (8)$$

As per the Barkhausen criterion $\angle A\beta = 0^{0}$

Now the angle of numerator term of the equation (8) is 0^0 hence to have angle of the $A\beta$ term as 0^0, the imaginary part of the denominator term must be zero.

$$\alpha^3 - 4k\alpha - 6\alpha = 0$$

$$\alpha = \sqrt{4k+6}$$

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

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

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

This the frequency at which < Aβ=0 ^{0} at the same frequency |Aβ|=1

Substituting $\alpha = \sqrt{4k+6}$ in equation (8) we get

$$h_{fe} = 4k + 23 + \frac{29}{k}$$

This must be the value of h_{fe} for the oscillations.

To get minimum value of h_{fe}

K = 2.6925 for minimum h_{fe}

$(h_{fe})min = 44.54$

- Thus for the circuit to oscillate, we must select the transistor whose ( ) should be greater than 44.54
- By changing the values of R and C, the frequency of the oscillator can be changed.
- But the value of R and C of all three sections must be changed simultaneously to satisfy the oscillating conditions. But this is practically impossible. Hence the phase shift oscillator is considered as a fixed oscillator, For all practical purpose.

RC phase shift oscillator using OP-amp

- It consists of a negative gain amplifier (-*K*) with a three-section (third-order) RC ladder network in the feedback.
- the circuit will oscillate at the frequency for which the phase shift of the RC network is 180^0

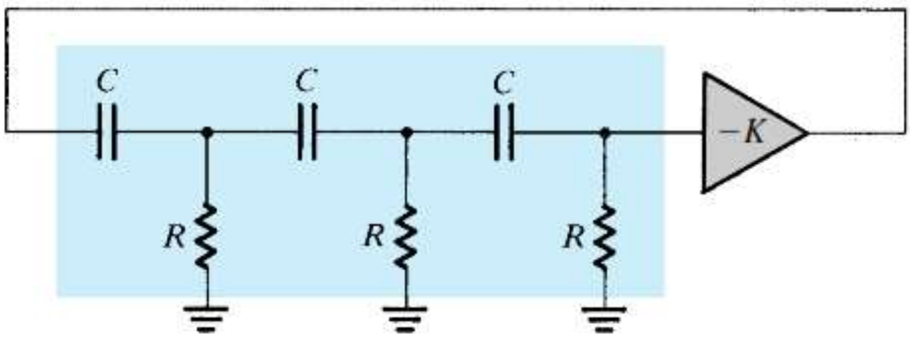


Figure: 2.2.2 RC phase shift oscillator using OP-amp

[Source: Microelectronic circuits by sedra and smith, Page-1345]

- The frequency of oscillation is given by

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

- At this frequency

$$|\beta| = \frac{1}{29}$$

- To have oscillation

$$|A| \geq \frac{1}{\beta} \geq 29$$

2.7 RING AND CRYSTAL OSCILLATOR

RING OSCILLATOR:

- The ring oscillator is a type of phase shift oscillator which is commonly used in digital integrated circuit for the generation of clock.
- It is cascaded combination of inverters, connected in a closed loop chain
- It consists of an odd number of CMOS inverters.
- The output of each inverter is used as input for the next inverter. The last output is fed back to the first inverter.
- As overall circuit forms a ring, it is called ring oscillator. the load used for each inverter is a capacitor.
- It can provide high frequency range
- It has a low power dissipation
- The figure 2.7.1 is ring oscillator using three inverter

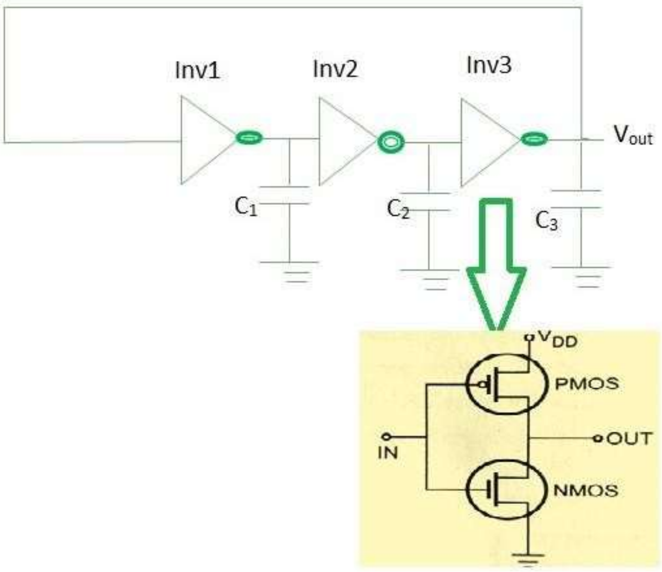


Figure 2.7.1 ring oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-413]

- The frequency of the clap oscillator is stable and accurate
- The CMOS inverter consists of a PMOS and NMOS transistor with capacitor as an additional delay element at its output.
- To have sustained oscillations, the total phase shift around a ring must be multiplies of 360^0 with unity voltage gain at the frequency of oscillation, to

satisfy Barkhausen criterion.to satisfy this in 'n' stage ring oscillator, teach stage provides a phase shift of $\frac{180}{n}$ and dc inversion provides a phase shift of 180^0

- The frequency of the ring oscillator depends on the propagation delay per inverter stage and the number of such stages used.

$$f = \frac{1}{2\pi\tau_d} HZ$$

CRYSTAL OSCILLATOR:

- The principle of crystal oscillators depends upon the Piezo electric effect.
- The natural shape of a crystal is hexagonal. When a crystal wafer is cut perpendicular to X-axis, it is called as X-cut and when it is cut along Y-axis, it is called as Y-cut.
- The crystal used in crystal oscillator exhibits a property called as Piezo electric property. So, let us have an idea on piezo electric effect.

Piezo Electric Effect

- The crystal exhibits the property that when a mechanical stress is applied across one of the faces of the crystal, a potential difference is developed across the opposite faces of the crystal. Conversely, when a potential difference is applied across one of the faces, a mechanical stress is produced along the other faces. This is known as Piezo electric effect.
- Certain crystalline materials like Rochelle salt, quartz and tourmaline exhibit piezo electric effect and such materials are called as Piezo electric crystals. Quartz is the most commonly used piezo electric crystal because it is inexpensive and readily available in nature.
- When a piezo electric crystal is subjected to a proper alternating potential, it vibrates mechanically. The amplitude of mechanical vibrations becomes maximum when the frequency of alternating voltage is equal to the natural frequency of the crystal

Working of a Quartz Crystal

- In order to make a crystal work in an electronic circuit, the crystal is placed between two metal plates in the form of a capacitor. Quartz is the mostly used type of crystal because of its availability and strong nature while being inexpensive. The ac voltage is applied in parallel to the crystal.

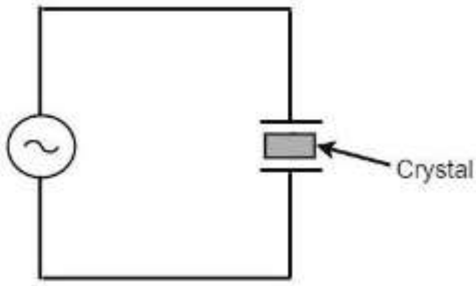


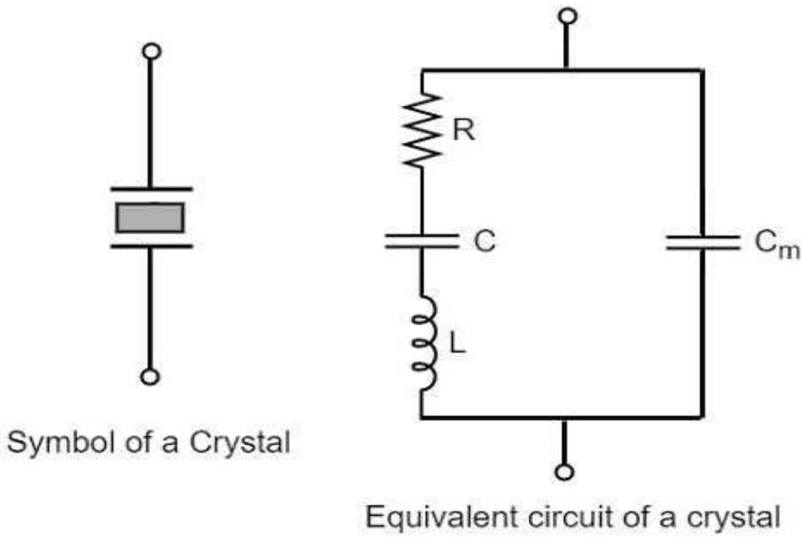
Figure 2.7.2 Quartz Crystal

[Source: Microelectronics byJ. Millman and A. Grabel, Page-423]

- If an AC voltage is applied, the crystal starts vibrating at the frequency of the applied voltage. 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.

Equivalent circuit of a Crystal

- If we try to represent the crystal with an equivalent electric circuit, we have to consider two cases, i.e., when it vibrates and when it doesn't. The figures below represent the symbol and electrical equivalent circuit of a crystal respectively.



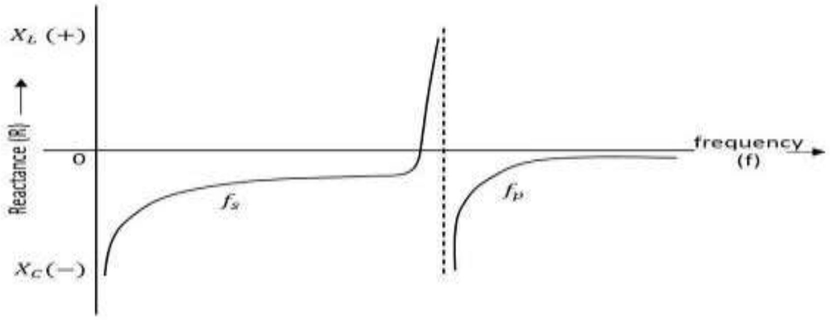
2.7.3. Symbol and Equivalent circuit of crystal

[Source: Microelectronics by J. Millman and A. Grabel, Page-423]

- The above equivalent circuit consists of a series R-L-C circuit in parallel with a capacitance C_m. When the crystal mounted across the AC source is not vibrating, it is equivalent to the capacitance C_m. When the crystal vibrates, it acts like a tuned R-L-C circuit.

Frequency response

- The frequency response of a crystal is as shown below. The graph shows the reactance (X_L or X_C) versus frequency (f). It is evident that the crystal has two closely spaced resonant frequencies.



2.7.4. Frequency Response

[Source: Microelectronics by J. Millman and A. Grabel, Page-486]

- The first one is the series resonant frequency (f_s), which occurs when reactance of the inductance (L) is equal to the reactance of the capacitance C. In that case, the impedance of the equivalent circuit is equal to the resistance R and the frequency of oscillation is given by the relation,

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

- The second one is the parallel resonant frequency (f_p), which occurs when the reactance of R-L-C branch is equal to the reactance of capacitor C_m. At this frequency, the crystal offers very high impedance to the external circuit and the frequency of oscillation is given by the relation.

$$f_p = \frac{1}{2\pi\sqrt{LCeq}}$$

Where,

$$C_{eq} = \frac{C_M C}{C_M + C}$$

- The value of C_m is usually very large as compared to C. Therefore, the value of C_T is approximately equal to C and hence the series resonant frequency is approximately equal to the parallel resonant frequency (i.e., $f_s = f_p$).
- The expression for resonating frequency,

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

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

- Q factor of the crystal is very high.(10^6)

$\sqrt{\frac{Q^2}{1+Q^2}}$ factor is unity hence $f_r = \frac{1}{2\pi\sqrt{LC}}$

$Q \propto \frac{1}{t}$; t- thickness of crystal

Crystal Oscillator Circuit

- A crystal oscillator circuit can be constructed in a number of ways like a Crystal controlled tuned collector oscillator, a Colpitts crystal oscillator, a Clap crystal oscillator etc. But the transistor pierce crystal oscillator is the most commonly used one. This is the circuit which is normally referred as a crystal oscillator circuit.
- The following circuit diagram shows fig 2.7.5 the arrangement of a transistor pierce crystal oscillator.

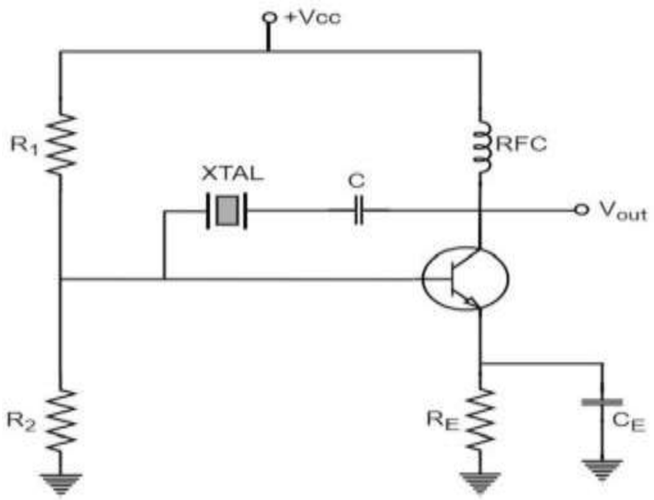


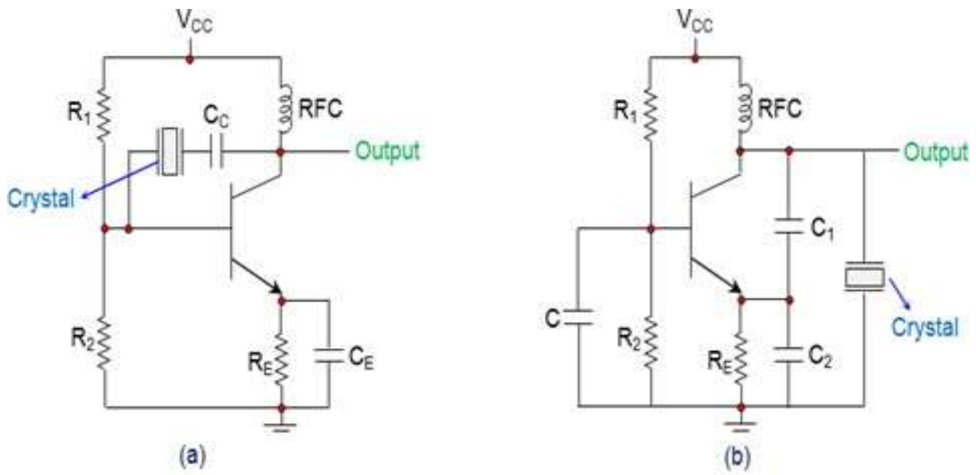
Figure 2.7.5 Transistor pierce crystal oscillator

'[Source: Microelectronics by J. Millman and A. Grabel, Page-418]

- In this circuit, the crystal is connected as a series element in the feedback path from collector to the base. The resistors R_1, R_2 and R_E provide a voltage-divider stabilized d.c. bias circuit.
- The capacitor C_E provides a.c. bypass of the emitter resistor and RFC (radio frequency choke) coil provides for d.c. bias while decoupling any a.c. signal on the power lines from affecting the output signal. The coupling capacitor C has negligible impedance at the circuit operating frequency. But it blocks any d.c. between collector and base.
- The circuit frequency of oscillation is set by the series resonant frequency of the crystal and its value is given by the relation,

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

- It may be noted that the changes in supply voltage, transistor device parameters etc. have no effect on the circuit operating frequency, which is held stabilized by the crystal.
- Crystal Oscillators can be designed by connecting the crystal into the circuit such that it offers low impedance when operated in series-resonant mode (Fig. 2.7.6 a) and high impedance when operated in anti-resonant or parallel resonant mode (Figure 2.7.6 b).



Crystal Oscillator Operating in (a) Series Resonance (b) Parallel Resonance

2.7.6 Series resonance and Parallel resonance in crystal oscillator circuit

[Source: Microelectronics byJ. Millman and A. Grabel, Page-419]

- In this circuit R_1 and R_2 form the voltage divider network while the emitter resistor R_E stabilizes the circuit. Further, C_E (Figure 2.7.6 a) acts as an AC bypass capacitor while the coupling capacitor C_C (Figure2.7.6 a) is used to block DC signal propagation between the collector and the base terminals.
- The capacitors C_1 and C_2 form the capacitive voltage divider network in the case of Figure 2.7.6 b.
- There is also a Radio Frequency Coil (RFC) in the circuits which offers dual advantage as it provides even the DC bias as well as frees the circuit-output from being affected by the AC signal on the power lines.

Advantages

1. They have a high order of frequency stability.
2. The quality factor (Q) of the crystal is very high.