2

Oscillators

2.1 INTRODUCTION

An oscillator is a circuit that produces a periodic waveform on its output with only the DC supply voltage as input. Oscillator is a source of AC voltage (or) current.

Any circuit which is used to produce a repetitive waveform without any AC input signal is called as oscillator.

An amplifier is different from oscillator in the sense that an amplifier requires some AC input which will be amplified. But an oscillator doesn't need any external AC signal. This is shown in figure 2.1.

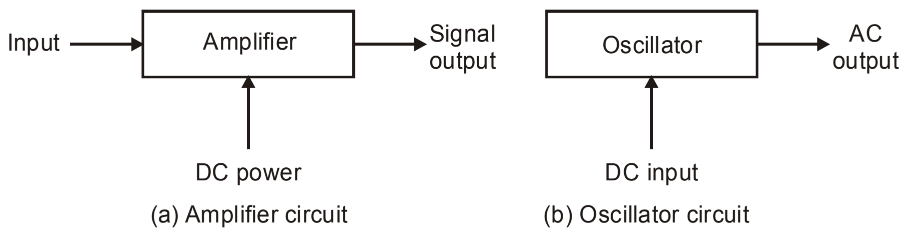


Figure 2.1: Difference between Amplifier and Oscillator

Oscillator operation is based on positive feedback whereby portion β of the output signal V_{out} is feedback without phase change which means that there is no phase difference between the input and feedback signal.

2.1.1 Comparison between Amplifier and Oscillator

For an amplifier, the additional power due to amplification is derived from the DC bias supply. So an amplifier effectively converts DC to AC. But it needs AC input. Without AC input, there is no AC output.

In the oscillator circuits also DC power is converted to AC. But there is no AC input signal. So the difference between amplifier and oscillator is in amplifiers circuits, the DC power conversion to AC is controlled by the AC input signal. But in oscillators, it is not so.

2.2 CLASSIFICATION OF OSCILLATORS

Oscillator can be classified as shown in figure 2.2.

1. Based on generated waveform
2. Based on fundamental mechanisms

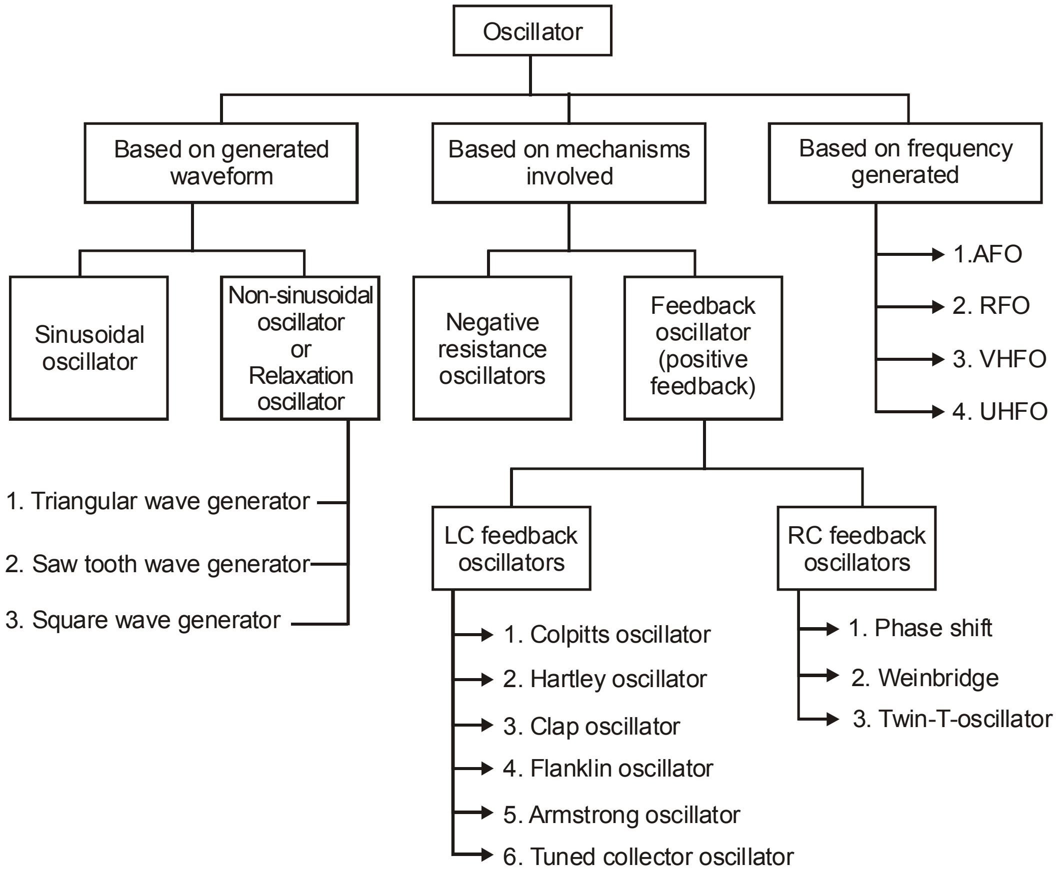


Figure 2.2: Classification of Oscillator

2.2.1 Based on generated waveform

Based on generated waveform can be classified as follows,

1. Sinusoidal oscillator
2. Relaxation oscillator

1. Sinusoidal Oscillator (Harmonic Oscillators)

It produces a sine-wave output signal. Output signal is of constant amplitude with no variation in frequency. It produce signals ranging from low audio frequencies to ultra high radio and microwave frequencies.

2. Relaxation Oscillators (Non-sinusoidal Oscillators)

It uses RC timing circuit to generate a non-sinusoidal waveform. It uses Schmitt trigger that changes states to alternatively charge and discharge a capacitor through a resistor. Generated voltages or current vary abruptly one or more times in a cycle of oscillation.

2.2.2 Based on Fundamental Mechanisms

Based on fundamental mechanisms involved,

1. Negative Resistance oscillators
2. Feedback oscillators

1. Negative Resistance Oscillators

It uses negative resistance of the amplifying device to neutralize the positive resistance of oscillator.

2. Feedback Oscillators

It uses positive feedback in feedback amplifier to satisfy Barkhausen criterion.

2.2.3 Based on frequency generated

1) Audio Frequency Oscillator (AFO): up to 20 KHz
2) Radio Frequency Oscillator (RFO): 20 KHz to 30 MHz
3) Very High Frequency Oscillator (VHFO): 30 MHz to 300 MHz
4) Ultra High Frequency Oscillator (UHFO): 300 MHz to 3 GHz
5) Microwave Frequency Osicllator (MFO): Above 3 GHz

2.2.4 Based on circuit type used

a) LC Tuned Oscillator
b) RC Phase Shift Oscillator

2.3 BASIC THEORY OF OSCILLATION

Positive feedback is characterised by part of output voltage is feedback to the amplifier as input with in phase with original input applied to amplifier.

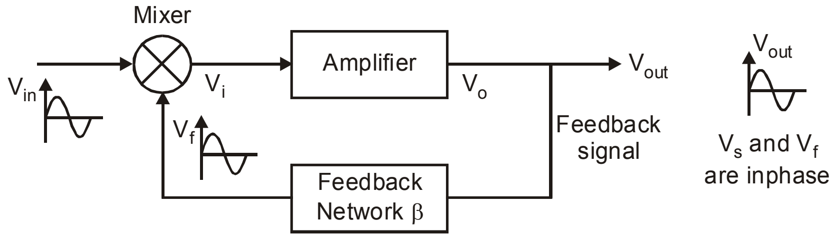


Figure 2.3 Block diagram of Oscillator

Feedback network decides amount of output is feedback to input. As the phase of feedback signal is same as that of input applied, then feedback is called *positive feedback.* In phase feedback voltage is amplified to produce the output voltage which in turn produce the feedback voltage.

Oscillator Gain without Feedback

Amplifier gain is A_V, i.e, it amplifies its input V_i, A times to produce output V_o.

$$\text{Gain, } A_V = \frac{V_{out}}{V_i} \qquad \text{... (2.1)}$$

where A_V – Open loop voltage gain

This is called as open loop gain of amplifier.

Oscillator Gain with Feedback

Closed loop gain is defined as ratio of output voltage V_{out} to input voltage V_{in} with including effect of feedback.

$$A_f = \frac{V_{out}}{V_{in}} \qquad \text{... (2.2)}$$

If Feed back is positive, V_f is added to V_{in} to produce input of Amplifier.

$$V_i = V_{in} + V_f$$

Feeback voltage $V_f = \beta V_o$

$$V_i = V_{in} + \beta V_o$$

Then $V_{in} = V_i - \beta V_o$

Substitute V_{in} in A_f, so

$$A_f = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_i - \beta V_o}$$

If Feed back is negative, V_f is subtracted from V_{in} to produce input of Amplifier.

$$V_i = V_{in} - V_f$$

Feeback voltage $V_f = \beta V_o$

$$V_i = V_{in} - \beta V_o$$

Then $V_{in} = V_i + \beta V_o$

$$A_f = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_i + \beta V_o}$$

Divide Numerator and Denominator by V_i,

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

$$A_f = \frac{A}{1 - A\beta} \quad ...2.3(a)$$

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

$$A_f = \frac{A}{1 + A\beta} \quad ...\ 2.3(b)$$

This gain is used for oscillator.

Practical Consideration

Feedback increases as the amount of positive feeback increases. At a particular point ($\beta < 1$), the gain becomes infinite. It clearly describes that circuit can produce output without external input ($V_{in} = 0$), just by feeding the part of output as its own input.

A	**B**	A_f
20	0.004	21.73
20	0.04	100
20	0.045	200
20	0.05	∞

At that time output cannot be infinite but drivens into oscillation. Simply we can conclude that circuit stops amplifying and starts oscillating. β is always fraction so $\beta < 1$. If $|A\beta| > 1$, circuit adjust itself to $|A\beta| = 1$ to produce oscillation.

2.3.1 Mechanism of start of oscillation

The starting voltage is provided by noise, which is produced due to random motion of electrons in resistors used in the circuit. The noise voltage contains almost all the sinusoidal frequencies. This low amplitude noise voltage gets amplified and appears at the output terminals.

The amplified noise drives the feedback network which is the phase shift network. Because of this the feedback voltage is maximum at a particular frequency, which in turn represents the frequency of oscilation.

Even when no external signal is applied, the ever present noise will cause some small signal at the output of amplifier.

When the amplifier is tuned at a particular frequency f_0, the output signal caused by noise signal will be predominantly at f_o.

If a small fraction (β) of the output signal is feedback to the input with proper phase relation, then this feedback signal will be amplified by the amplifier. If the amplifier has a gain more than $1/\beta$, then the output increases and thereby the feedback signal becomes larger. This process continues and the output goes in increasing.

But as the signal level increases, the gain of the amplifier decreases and at a particular value of output the gain of the amplifier is reduced exactly equal to $1/\beta$. Then the voltage remains constant at frequency f_o, called frequency of oscillation.

2.4 BARKHAUSEN CRITERION

Let us consider Non-Inverting Amplifier as shown below.

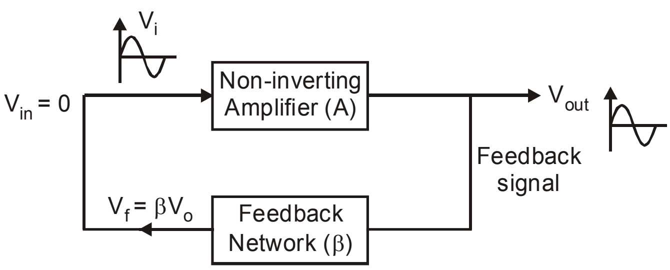


Figure 2.4: Barkhausen Criterion

Input voltage V_i is applied to non-inverting amplifier, so

$$V_{out} = AV_i \quad \text{... (2.4)}$$

Feedback factor β decides the feedback to be given to input

$$V_f = \beta V_{out} \quad \text{... (2.5)}$$

$$\Rightarrow \quad V_{out} = V_f / \beta$$

Substitute equation (2.4) in equation, (2.5)

$$V_f = A\beta V_i$$

For oscillator, feedback signal must drive the amplifier, so V_f must act as V_i.

$$V_f = V_i$$

So,
$$V_i = A\beta V_i$$

This will satisfy only when

$$A\beta = 1 \text{ or } |A\beta| = 1 \quad \text{... (2.6)}$$

This condition is called as *Barkhausen criterion.*

In this condition, V_f drives the circuit without external input (V_{in}).

So the circuit works as an oscillator.

The essential conditions for maintaining oscillations are

1) Magnitude of loop gain must be unity. i.e. $|A\beta| = 1$.
2) Total phase shift around closed loop is zero or 360°.

Case $|A\beta| > 1$ (Amplitude Keeps on Increasing)

When the total phase shift around a loop is 0° or 360° with $|A\beta| > 1$, then the oscillation output are of *growing type*.

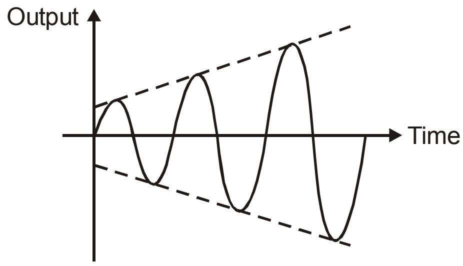


Figure 2.5: Growing type of oscillation

Case $|A\beta| = 1$ (Constant Amplitude and Frequency)

When the total phase shift around a loop is 0° or 360°, with $|A\beta| = 1$, then the oscillation output must have *sustained oscillations*.

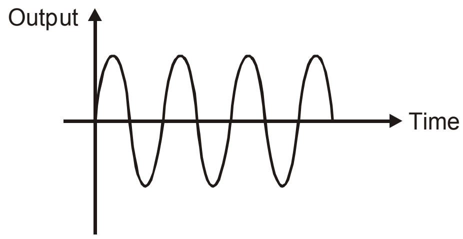


Figure 2.6: Sustained oscillation

Case $|A\beta| < 1$ (Amplitude decreases exponentially)

When the total phase shift around a loop is 0° or 360° but $|A\beta| > 1$, then the oscillation output are of *decaying type*.

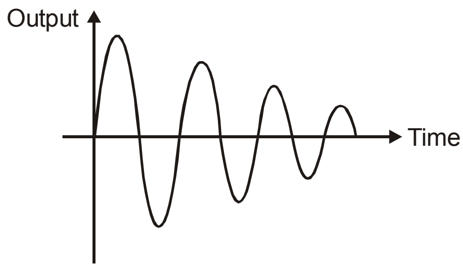


Figure 2.7: Decaying type of oscillation

2.5 BASIC LC OSCILLATOR

The circuit consists of an inductive coil, L and a capacitor, C to produce the oscillations are called LC **oscillators**. L and C forms LC tank circuit. This circuit is also called as **resonating circuit or tuned circuit**. It has capable to produce high frequency so that only it is used for sources of RF energy.

Resonant Frequency

Resonant circuit that has a **Resonant Frequency**, (f_r) in which the capacitive and inductive reactance's are equal and cancel out each other, leaving only the resistance of the circuit to oppose the flow of current. This means that there is no phase shift as the current is in phase with the voltage.

2.5.1 Operation of LC tank circuit

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 voltage, V by putting the switch in position A. When the capacitor is fully charged the switch changes to position B as shown in Figure 2.8.

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 field is now stored in the inductive coil, L as an electromagnetic field around the coils windings.

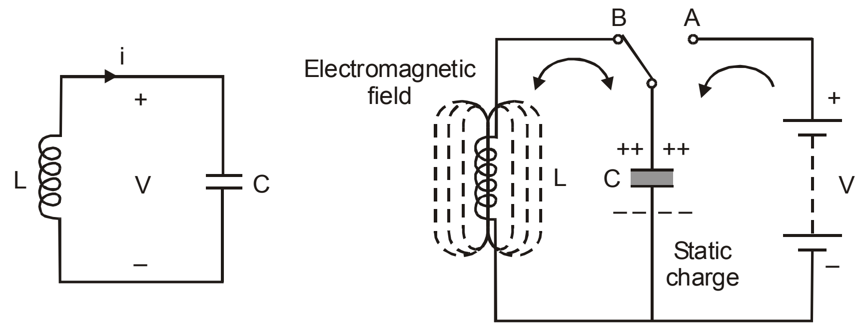


Figure 2.8: Basic LC Oscillator tank circuit

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 charges up capacitor, C with the opposite polarity to its original charge. C continues to charge up until the current reduces to zero and the electromagnetic field of the coil has collapsed completely.

The energy originally introduced into the circuit through the switch, has been returned to the capacitor which again has an electrostatic voltage potential across it, although it is now of the opposite polarity. The capacitor now starts to discharge again back through the coil and the whole process is 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.

Every time energy is transferred from the capacitor, C to inductor, L and back from L to C some energy losses occur which decay the oscillations to zero over time.

This oscillatory action of passing energy back and forth between the capacitor, C to the inductor, L would continue indefinitely if it was not for energy losses within the circuit.

Then in a practical LC circuit the amplitude of the oscillatory voltage decreases at each half cycle of oscillation and will eventually die away to zero. The oscillations are then said to be "damped" with the amount of damping being determined by the quality or Q-factor of the circuit.

$$X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

At Resonance $X_C = X_L$

$$2\pi fL = \frac{1}{2\pi fC} \rightarrow 2\pi f^2L = \frac{1}{2\pi C}$$

$$f^2 = \frac{1}{(2\pi)^2 LC}$$

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

Then by simplifying the above equation we get the final equation for **Resonant Frequency**, f_r in a tuned LC circuit as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \qquad \text{... (2.7)}$$

where L is the inductance in Henries

C is the capacitance in Farads

f_r is the output frequency in Hertz

This equation shows that if either L or C are decreased, the frequency increases. This output frequency is commonly given the abbreviation of (f_r) to identify it as the "resonant frequency".

Replacing the energy

To keep the oscillations going in an LC tank circuit, we have to replace all the energy lost in each oscillation and also maintain the amplitude of these oscillations at a constant level. **The amount of energy replaced must therefore be equal to the energy lost during each cycle**.

The simplest way of replacing this lost energy is to take part of the output from the LC tank circuit, amplify it and then feed it back into the LC circuit again.

However, if the loop gain of the feedback amplifier is too small, the desired oscillation decays to zero and if it is too large, the waveform becomes distorted.

Constant oscillation production

To produce a constant oscillation, the level of the energy feed back to the LC network must be accurately controlled. Then there must be some form of automatic amplitude when the amplitude tries to vary from a reference voltage either up or down.

To maintain a stable oscillation the overall gain of the circuit must be equal to one or unity. Any less and the oscillations will not start or die away to zero, any more the oscillations will occur but the amplitude will become clipped by the supply rails causing distortion.

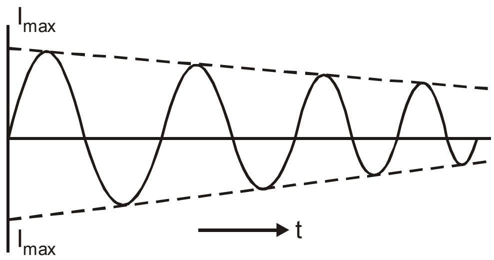


Figure 2.9: Damped Oscillation

2.5.2 General form of Oscillator

In general form of oscillator, any of active devices such as BJT, FET, and OP-AMP may be used in amplifier section.

Frequency of oscillation can be determined by reactive elements (Z_1, Z_2 and Z_3) constituting feedback tank circuit.

Here, Z_1 and Z_2 serve as an AC voltage divider for the output voltage and feedback signal.

$\because$ The voltage across Z_1 is the feedback signal.

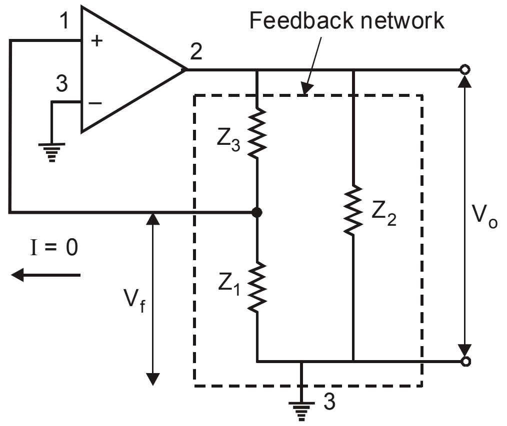


Figure 2.10: General form of oscillator

The frequency of oscillation of LC oscillator is

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

The inductive or capacitive reactance are represented by Z_1, Z_2 and Z_3.

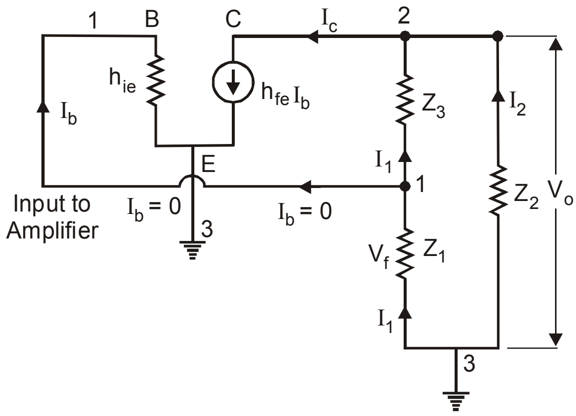


Figure 2.11: Equivalent circuit

Load Impedence

In figure 2.11 Z_1 and input resistance h_{ie} of BJT are in parallel, then the equivalent impedence Z' is

$$Z' = Z_1 || h_{ie} \Rightarrow \frac{Z_1 \times h_{ie}}{Z_1 + h_{ie}} \qquad \text{... (2.8)}$$

Load impedance Z_L between output terminals 2 and 3 is the equivalent impedence of Z_2 in parallel with series combination of Z' and Z_3.

i.e., $$Z_L = Z_2 || (Z' + Z_3) \Rightarrow \frac{Z_2 \times (Z' + Z_3)}{Z_2 + Z' + Z_3} \qquad \text{... (2.9)}$$

Substituting equation (2.8) in the equation (2.9),

$$Z_L = \frac{Z_2 \times \left[\dfrac{Z_1 \times h_{ie}}{Z_1 + h_{ie}}\right] + Z_2 Z_3}{Z_2 + \dfrac{Z_1 \times h_{ie}}{Z_1 + h_{ie}} + Z_3}$$

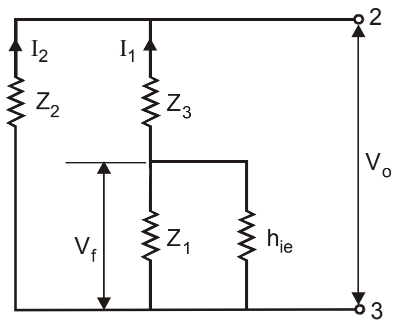


Figure 2.12: Load impedance

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

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

$$Z_L = \frac{Z_2 \left[h_{ie} (Z_1 + Z_3) + Z_1 Z_3\right]}{h_{ie} (Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \qquad \text{... (2.10)}$$

Voltage gain without feedback

It is expressed as follows:

$$A_v = \frac{V_o}{V_i}, \; V_o = -h_{fe}\, I_b (Z_L), \; V_i = I_b\, h_{ie} A_v = \frac{-h_{fe} Z_L}{h_{ie}} \qquad \text{... (2.11)}$$

Note: – sign indicates that amplifier stage introduces 180° phase shift.

Feedback fraction (β)

Output voltage between the terminals 3 and 2 interms of current I_1 is given by,

$$V_o = -I_1 \ (Z' + Z_3)$$

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

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

$$V_o = I_1 \left(\frac{h_{ie} \left(Z_1 + Z_3\right) + Z_1 \, Z_3}{Z_1 + h_{ie}} \right) \qquad \text{... (2.12)}$$

Voltage feedback to input terminals 3 and 1 is given by,

$$V_f = -I_1 \ Z'$$

$$V_f = -I_1 \left(\frac{Z_1 \, h_{ie}}{Z_1 + h_{ie}} \right) \qquad \text{... (2.13)}$$

∵ Feedback Ratio β is given by,

$$\beta = \frac{V_f}{V_o} = \frac{-I_1 \left(\dfrac{Z_1 \, h_{ie}}{Z_1 + h_{ie}} \right)}{-I_1 \left(\dfrac{h_{ie} \left(Z_1 + Z_3\right) + Z_1 \, Z_3}{Z_1 + h_{ie}} \right)}$$

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

$$\boxed{\beta = \frac{Z_1 \ h_{ie}}{h_{ie}\left(Z_1 + Z_3\right) + Z_1 \, Z_3}} \qquad \text{... (2.14)}$$

Equation of Oscillator

For sustained oscillation, $A_v\beta = 1$.

So substitute equation (2.11) and equation (2.14) in $|AB| = 1$.

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

Substituting equation (2.10) in above equation, we get

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

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

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

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

$$h_{ie} (Z_1 + Z_2 + Z_3) + (1 + h_{fe}) Z_1 Z_2 + Z_1 Z_3 = 0 \quad \text{... (2.15)}$$

This is the general equation for the oscillator.

Frequency of Oscillation

The feedback circuit must introduce 180º phase shift so,

$$Z_1 + Z_2 + Z_3 = 0$$

Frequency of oscillation, $f_o = \frac{\omega_o}{2\pi}$ can be determined by considering only imaginary part of general equation.

Sustained Oscillation

The condition for maintenance of oscillation is obtained by substituting f_o in equation and considering only real part.

2.5.3 Types of LC Oscillator

Depending on the design of reactance Z_1, Z_2 and Z_3 LC oscillator can be classified as,

1. Hartley oscillator ($Z_1 = Z_2 = L$ and $Z_3 = C$)
2. Colpitts oscillator ($Z_1 = Z_2 = C$ and $Z_3 = L$)
3. Clapp oscillator($Z_1 = Z_2 = C$ and Z_3 = series combination of L and C)
4. Franklin oscillator
5. Armstrong oscillator

2.6 HARTLEY OSCILLATOR

Hartley oscillator was invented in 1915 by the American Engineer Ralph Hartley.

If the LC oscillator uses two inductive reactances and one capatitive reactance in its feedback network, it is called as *Hartely oscillator*.

In the **Hartley oscillator** the tuned LC circuit is connected between the collector and the base of a transistor amplifier.

2.6.1 Construction of Hartley Oscillator using BJT

An Hartley Oscillator circuit can be made from any configuration that uses either a single tapped coil (similar to an autotransformer) or a pair of series connected coils in parallel with a single capacitor as shown below in figure 2.13.

The resistances R_1, R_2 and R_E provides the necessary D.C bias to the transistor. CE is a bypass capacitor. C_b and C_c are coupling capacitor to provide the stable Q point. The feedback network consists of inductors L_1 and L_2 and Capacitor C determines the frequency of oscillator.

If the coil L is centre-tapped, then the Hartley circuit is often referred to as a **split-inductance oscillator**, because inductance L acts like two separate coils in very close proximity with the current flowing through coil section 23 induces a signal into coil section 31 below.

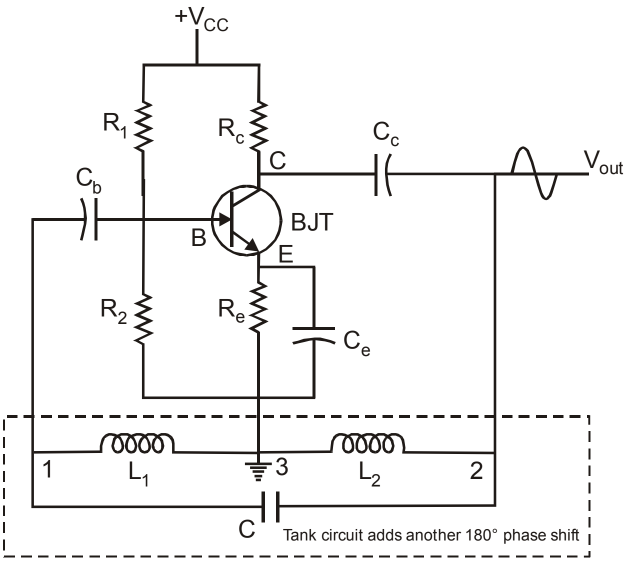


Figure 2.13: Hartley Oscillator

2.6.2 Operation of Hartley Oscillator

When the circuit is switched ON, a transient current is produced in the tank circuit and consequently, damped oscillations are set up in the circuit. The oscillatory current in the tank circuit produces AC current across L_1 and L_2.

When the circuit is oscillating, the voltage at point 2 (collector), relative to point 3 (emitter), is 180° out-of-phase with the voltage at point 1 (base) relative to point 3. At the frequency of oscillation, the impedance of the collector load is resistive and an increase in base voltage causes a decrease in the collector voltage.

Then there is a 180° phase change in the voltage between the base and collector and this along with the original 180° phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained. So the total phase shift is 360°. Thus, at the frequency determined for the tank circuit, the necessary condition for sustained oscillations is satisfied. If the feedback is adjusted so that the loop gain $A\beta = 1$, the circuit acts as an oscillator.

For center tapped inductor, the amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa.

2.6.3 Derivation of Frequency of Oscillation

Equivalent circuit of Hartley oscillator is shown in figure 2.14.

From figure 2.14 we come to know that,

$h_{fe}I_b$ – Output collector current

I_b – Base current

Z_1 – Inductance reactance between Base and emitter i.e., $Z_1 = j\omega L_1 + j\omega M$

M – Mutual inductance

Z_2 – Inductance reactance between collector and emitter i.e., $Z_2 = j\omega L_2 + j\omega M$

Z_3 – Capacitive reactance between base and collector i.e., $Z_3 = \dfrac{1}{j\omega C} = . -\dfrac{j}{\omega C}$

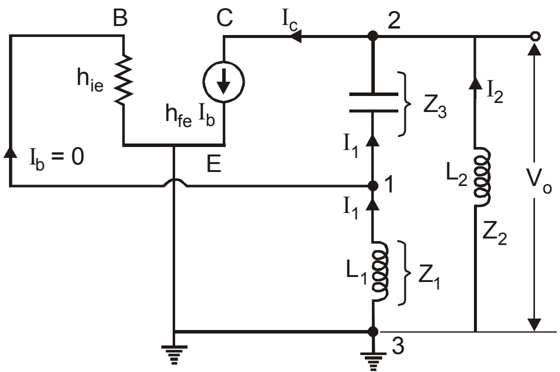


Figure 2.14: Equivalent Circuit of Hartley Oscillator

The general form of oscillator is,

$$h_{ie}\ (Z_1 + Z_2 + Z_3) + Z_1\ Z_2\ (1 + h_{fe}) + Z_1\ Z_3 = 0 \text{ (from equation 2.15)}$$

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

Substitute value of Z_1, Z_2 and Z_3 in above equation,

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

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

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

$$j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] - \omega^2(L_1 + M)\left[(L_2 + M)(1 + h_{fe}) - \frac{1}{\omega^2 C}\right] = 0 \quad \text{... (2.16)}$$

The frequency of oscillation $f_o = \frac{\omega_o}{2\pi}$ can be determined by considering only imaginary part of general equation 2.16.

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

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

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

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

Then
$$f_o = \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{C(L_1 + L_2 + 2M)}} = \frac{0.159}{\sqrt{C(L_1 + L_2 + 2M)}}$$

This equation is *frequency of oscillation.*

If $L_1 + L_2 + 2M = L_{eq}$ then $f = \frac{1}{2\pi\sqrt{L_{eq} C}}$

If $L_1 = L_2 = L$ without considering mutual induction, then $f = \frac{1}{2\pi\sqrt{2LC}}$

The *condition for maintenance of oscillation* is obtained by considering only real part of equation (2.16).

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

Then $(L_2 + M)\ (1 + h_{fe}) = \dfrac{1}{\omega^2 C}$

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

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

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

Above h_{fe} expression is required to satisfy the oscillating conditions.

2.6.4 Hartley oscillator using FET

If the FET is used an active device in an amplifier stage, then the oscillator circuit is called as FET Hartley oscillator. Figure 2.15 shows the FET Hartley oscillator.

The resistances R_1, R_2 and R_E provides the necessary DC bias to the transistor. C_E is a bypass capacitor. C_b and C_c are coupling capacitor. The feedback network consists of inductors L_1 and L_2 and Capacitor C determines the frequency of oscillator.

We know that $Z_1 = j\omega L_1 + j\omega M$, $Z_2 = j\omega L_2 + j\omega M$ and $Z_3 = \dfrac{1}{j\omega C} = -\dfrac{j}{\omega C}$

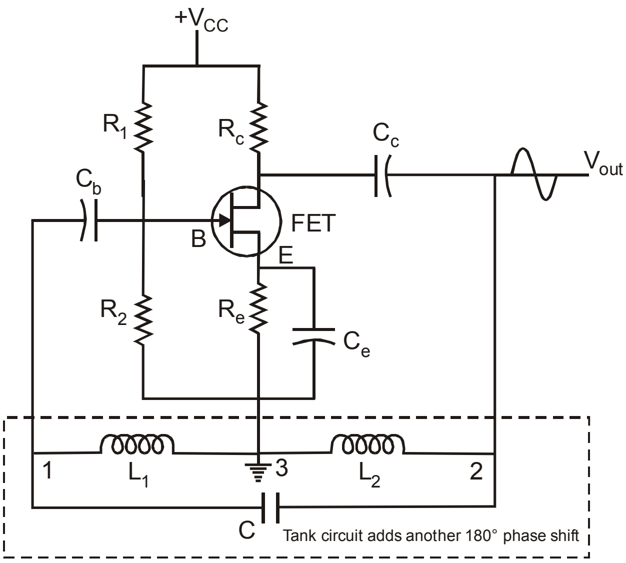


Figure 2.15: Hartley Oscillator using FET

Similar to previous section, solving for ω, the frequency of oscillation are obtained as follows,

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

2.6.5 Hartley oscillator using OP-AMP

If the OPAMP is used as active device in an amplifier stage, then the oscillator circuit is called as OPAMP Hartley oscillator. Figure 2.16 shows the OPAMP Hartley oscillator.

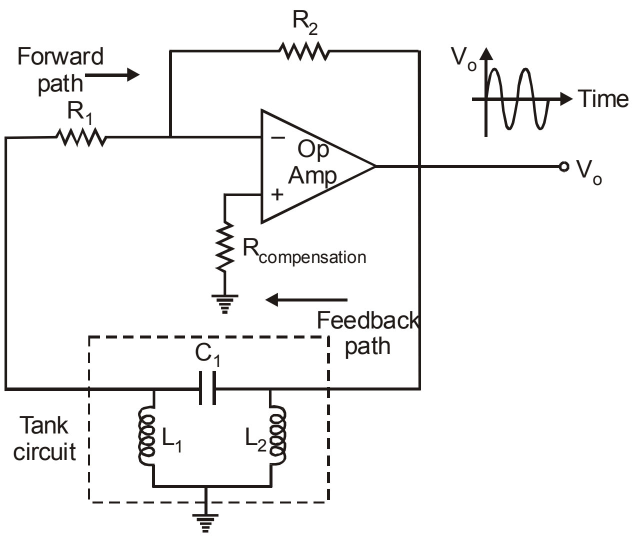


Figure 2.16: Hartley Oscillator using OPAMP

The advantage of constructing a Hartley oscillator using an operational amplifier as its active stage is that the gain of the op-amp can be very easily adjusted using the feedback resistors R_1 and R_2.

The gain of the circuit h_{fe} must be equal too or slightly greater than the ratio of L_1/L_2.

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

If the two inductive coils are wound onto a common core and mutual inductance M exists then the ratio becomes

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

Advantages of Hartley Oscillator

- Radio Frequency Choke (RFC) which connects the DC supply to the circuit but isolate the DC supply from the high frequency oscillations generated in the feedback circuit.
- More stable than Armstrong oscillators.
- Automatic base bias is possible.

Disadvantage of Hartley Oscillator

- Only low frequencies are used in Hartley oscillator.

Application of Hartley Oscillator

- Used in radio receivers and transmitters.

2.7 COLPITTS OSCILLATOR

The **Colpitts Oscillator**, named after its inventor Edwin Colpitts.

If the LC oscillator uses two capacitive reactances and one Inductive reactance in its feedback network, it is called as Colpitts oscillator. In the **Colpitts Oscillator**, the tuned LC circuit is connected between the collector and the base of a transistor amplifier.

2.7.1 Construction of Colpitts Oscillator using BJT

An Colpitts oscillator circuit can be made from any configuration that uses either a single tapped coil (similar to an autotransformer) or a pair of series connected coils in parallel with a single capacitor as shown in figure 2.17.

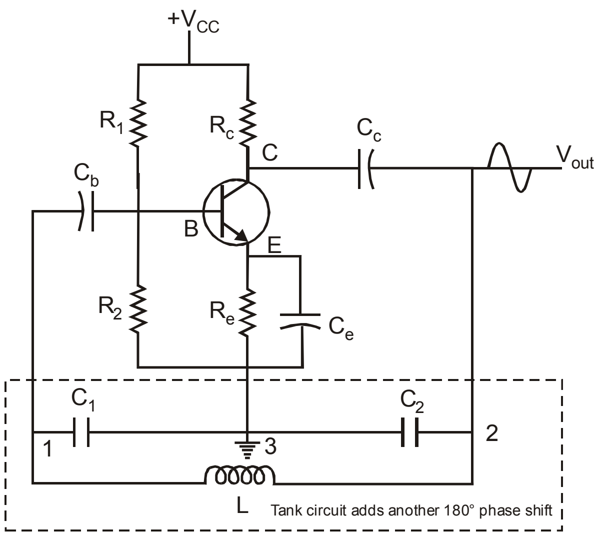


Figure 2.17: Colpitts Oscillator

The resistances R_1, R_2 and R_E provides the necessary DC bias to the transistor. C_E is a bypass capacitor. C_b and C_c are coupling capacitor to provide the stable Q point. The feedback network consists of capacitive C_1 and C_2 and inductor L determines the frequency of oscillator.

2.7.2 Operation of Colpitts Oscillator

When the circuit is switched ON, a transient current is produced in the tank circuit and consequently, damped oscillations are set up in the circuit. The oscillatory current in the tank circuit produces AC current across C_1 and C_2.

When the circuit is oscillating, the voltage at point 2 (collector), relative to point 3 (emitter), is 180° out-of-phase with the voltage at point 1 (base) relative to point 3. At the frequency of oscillation, the impedance of the collector load is resistive and an increase in base voltage causes a decrease in the collector voltage. Then there is a 180° phase change in the voltage between the base and collector and this along with the original 180° phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained. So the total phase shift is 360°.

Thus, at the frequency determined for the tank circuit, the necessary condition for sustained oscillations is satisfied. If the feedback is adjusted so that the loop gain $A\beta = 1$, the circuit acts as an oscillator.

2.7.3 Derivation of Frequency of oscillation

Equivalent circuit of Colpitts oscillator is shown in figure 2.18.

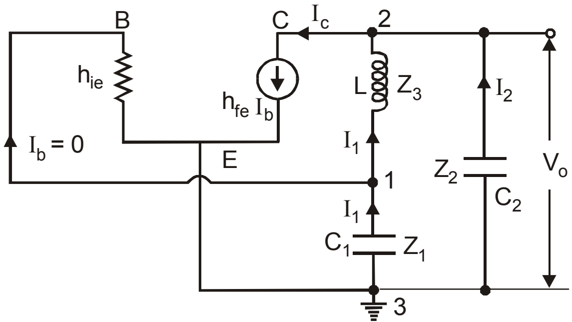


Figure 2.18: Equivalent Circuit of Colpitts oscillator

From figure 2.17, we come to know that where

$h_{fe}I_b$ – Output collector current.

I_b – Base current

Z_1 – Capacitive reactance between base and emitter i.e., $Z_1 = \dfrac{1}{j\omega C_1} = -\dfrac{j}{\omega C_1}$

M – Mutual inductance

Z_2 – Capactive reactance between collector and emitter i.e., $Z_2 = \dfrac{1}{j\omega C_2} = -\dfrac{j}{\omega C_2}$

Z_3 – Inductive reactance between base and collector i.e., $Z_3 = j\omega L$

We know that the general form of oscillator is,

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 (1 + h_{fe}) + Z_1 Z_3 = 0 \text{ (from equation 2.15)}$$

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

Substituting the value of Z_1, Z_2 and Z_3 in above equation,

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

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

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

$$jh_{ie}\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right) + \left[\frac{1 + h_{fe}}{\omega^2 C_1 C_2} - \frac{L}{C_1}\right] = 0 \qquad \text{... (2.17)}$$

Frequency of oscillation

Frequency of oscillation, $f_o = \dfrac{\omega_o}{2\pi}$ is obtained by equating imaginary part = 0 of equation (2.17),

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

Then

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

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

$$\frac{1}{C_1} + \frac{1}{C_2} = \omega^2 L \Rightarrow \omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) \qquad \text{... (2.18)}$$

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

Since $\omega = 2\pi f$ $\therefore$ then $2\pi f = \sqrt{\frac{1}{L}\left(\frac{C_1 + C_2}{C_1 C_2}\right)}$

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

C_1 and C_2 are connected in series, Then $C_{eq} = \frac{C_1 + C_2}{C_1 + C_2}$

$$\text{So,} \quad f = \frac{1}{2\pi\sqrt{LC_{eq}}} \qquad \text{... (2.19)}$$

Condition for sustained oscillation

Condition for sustained oscillation is obtained by considering only real part equation (2.17)

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

$$1 + h_{fe} = \frac{L\omega^2 \cdot C_2 C_1}{C_1} \Rightarrow L\omega^2 C_2$$

Substituting equation (2.19) in above equation

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

$$1 + h_{fe} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)C_2$$

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

$$\boxed{h_{fe} = \frac{C_2}{C_1}} \qquad \text{... (2.20)}$$

2.7.4 Colpitts Oscillator using FET

If the FET is used an active device in an amplifier stage of basic Colpitts oscillator, then the oscillator circuit is called as FET Colpitts oscillator. Figure 2.19 shows the FET Colpitts oscillator.

The resistances R_1, R_2 and R_E provides the necessary DC bias to the transistor. C_E is a bypass capacitor. C_b and C_c are coupling capacitor. The feedback network consists of capacitors C_1 and C_2 and inductor L determines the frequency of oscillator.

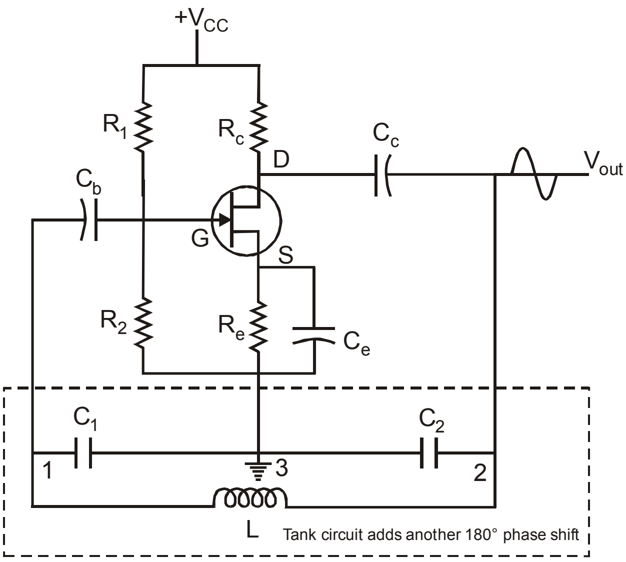


Figure 2.19: Colpitts Oscillator using FET

We know that $Z_1 = \dfrac{1}{j\omega C_1} = -\dfrac{j}{\omega C_1}$

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

and $Z_3 = j\omega L$

Similar to previous section, solving for ω, the frequency of oscillation are obtained as follows,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \quad \text{where } C = \frac{C_1 C_2}{C_1 + C_2}$$

2.7.5 Colpitts oscillator using OP-AMP

If the OPAMP is used an active device in an amplifier stage of basic Colpitts oscillator, then the oscillator circuit is called as OPAMP Colpitts oscillator. Figure 2.20 shows the OPAMP Colpitts oscillator.

The frequency of oscillation are obtained as follows,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \quad \text{where } C = \frac{C_1 C_2}{C_1 + C_2}$$

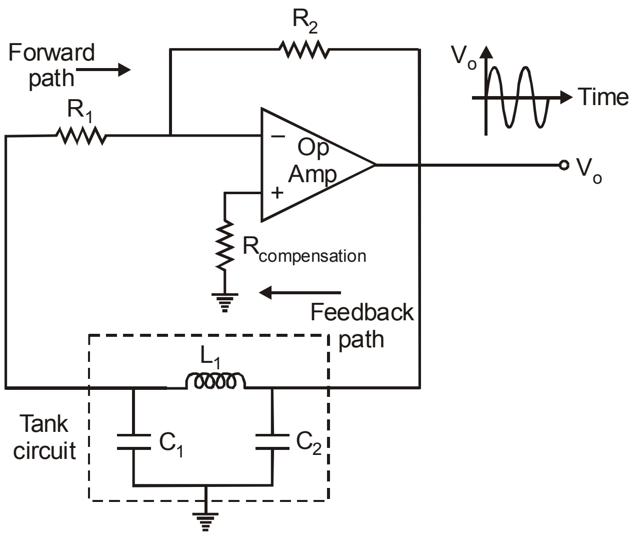


Figure 2.20: Colpitts Oscillator using OP-AMP

The gain of the circuit h_{fe} must be equal too or slightly greater than the ratio of L_1/L_2.

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

Advantages of Colpitts oscillator

1. Good wave purity.
2. Fine performer at high frequency.
3. Wide operation range 1 to 60 MHz.

Disadvantages of Colpitts oscillator

1. Poor frequency stability.
2. Diffcult to design.

2.8 CLAPP OSCILLATOR

Frequency stability of Colpitts oscillator can be improved by *Clapp oscillator.* If one more capacitance is added in series with inductance of tank circuit without modifying any other elements, then the oscillator is called as Clapp oscillator. *Clapp oscillator is modification of Colpitts oscillator.*

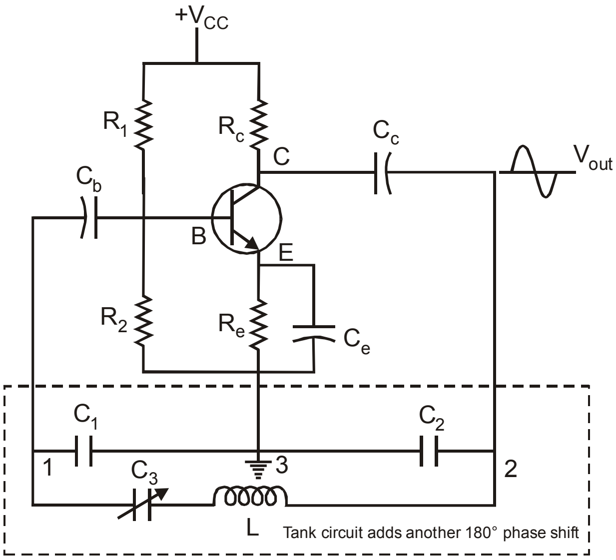


Figure 2.21: (a) Clapp Oscillator

2.8.1 Derivation of frequency of oscillation

Equivalent circuit of Clapp oscillator is shown in figure 2.21(b).

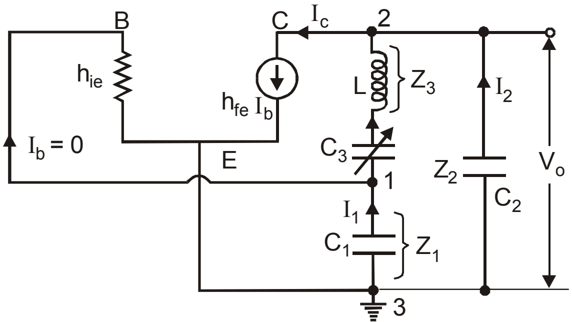


Figure 2.21: (b) Equivalent Circuit of Clapp oscillator

From figure 2.21(b), we come to know that, where

$h_{fe}I_b$ – Output Collector current.

I_b – Base current

Z_1 – Capacitive reactance between base and emitter i.e., $Z_1 = \frac{1}{j\omega C_1} = -\frac{j}{\omega C_1}$

M – Mutual inductance

Z_2 – Capactive reactance between collector and emitter i.e.,

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

Z_3 – Inductive reactance between base and collector i.e.,

$$Z_3 = j\omega L + \frac{1}{j\omega C_3} = j\omega L - \frac{j}{\omega C_3}$$

General form of oscillator is,

h_{ie} $(Z_1 + Z_2 + Z_3) + Z_1$ $[Z_2$ $(1 + h_{fe}) + Z_3] = 0$ (from 2.15)

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

$$-jh_{ie}\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L + \frac{1}{\omega C_3}\right) - \left(\frac{1}{\omega C_1}\right)\left[\frac{1}{\omega C_2}(1 + h_{fe}) - \omega L + \frac{1}{\omega C_3}\right] = 0 \quad \text{.... (2.21)}$$

Frequency of Oscillation

Frequency of oscillation is obtained by considering imaginary part and equating real part = 0 of equation (2.21),

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

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

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

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

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

Since $\omega = 2\pi f$; $2\pi f = \sqrt{\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)} \Rightarrow 2\pi f = \frac{1}{\sqrt{L}}\sqrt{\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)}$

C_1 C_2, C_2 and C_3 are in series so,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}} \qquad \text{... (2.22)}$$

If C_3 is much smaller than C_1 and C_2 then C_3 almost entirely controls the resonant frequency.

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

Condition for Sustained Oscillation

Condition for sustained oscillation is obtained by considering real part and equating imaginary part = 0 of equation (2.21),

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

$$-\frac{(1+h_{fe})}{\omega^2 C_1 C_2} + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_3} = 0$$

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

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

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

$$\frac{C_2}{C_1 C_2}\left(\omega^2 C_1 C_3 L - C_1\right) = 1 + h_{fe} \Rightarrow \quad \omega^2 C_2 L - \frac{C_2}{C_3} = 1 + h_{fe}$$

Since $\quad \omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$, then $\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) C_2 L - \frac{C_2}{C_3} = 1 + h_{fe}$

$$\frac{C_2 L}{LC_1} + \frac{C_2 L}{LC_2} + \frac{C_2 L}{LC_3} - \frac{C_2}{C_3} = 1 + h_{fe}$$

$$\frac{C_2}{C_1} + 1 + \frac{C_2}{C_3} - \frac{C_2}{C_3} = 1 + h_{fe}$$

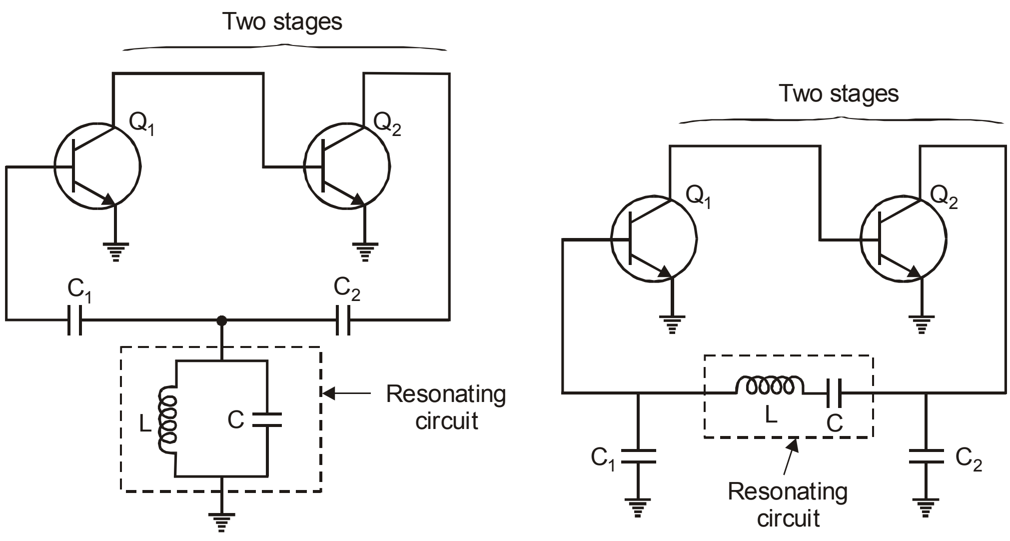
$$\boxed{h_{fe} = \frac{C_2}{C_1}} \qquad \text{... (2.23)}$$

2.8.2 Advantages of Clapp Oscillator

1. Frequency is accurate and stable.
2. By installing suitable sized switched capacitors into circuit, the power factor is improved.
3. The variable capacitance C_3 decides the frequency.

2.9 FRANKLIN OSCILLATOR

The Franklin oscillator uses a two-stage amplifier in conjunction with a parallel or series-tuned resonant tank circuit. In this circuit, each stage shifts phase 180° so that the total phase shift is 360° which is equivalent to zero phase shift. We may say that one stage serves as the phase inverting element in place of the RC or LC network which generally performs this function.



(a) Parallel resonating circuit (b) Series resonating circuit

Figure 2.22: Basics block of Franklin Oscillator

2.9.1 Types of Franklin Oscillator

Based on the isolation of two stages, it can be classified as,

1. Parallel resonating Franklin oscillator
2. Series resonating Franklin oscillator

2.9.2 Parallel Resonating Franklin Oscillator

In parallel Franklin oscillator, two small capacitance C_1 and C_2 are used to provide isolation.

In this type, L is connected in parallel with C to form Parallel resonating circuit. First stage with Q_1 provides 180° phase shift while second stage with Q_2 provides 180° phase shift, so total phase shift is 360 or 0° phase shift. First stage is interconnected with second stage via coupling resistance R_b.

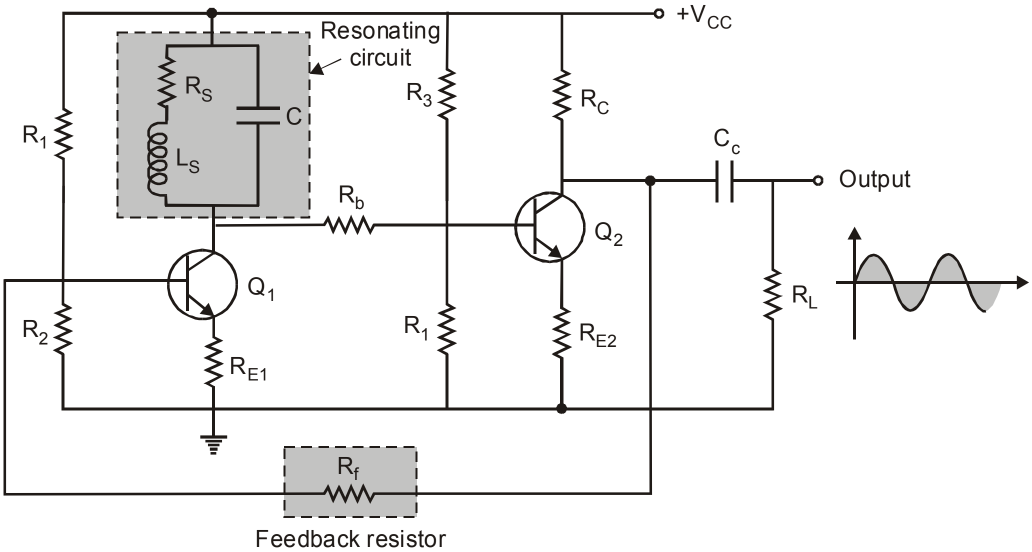


Figure 2.23: Parallel Resonating circuit for Franklin oscillator

Attenuation caused by coupling resistance R_b and feedback resistance R_f decides the over all loop gain $A\beta$. The values of all components of the circuit are chosen in such a way that the overall loop gain of these two states $|A\beta| > 1$.

The frequency of oscillation is expressed as follows:

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

Since it satisfies the both condition of Barhausen criteria are satisfied, then the circuit works as an oscillator.

Application:

Used to achieve frequencies range from 100 MHz to 33 GHz.

2.9.3 Series Franklin Oscillator

In series Franklin oscillator, two large capacitance C_1 and C_2 are used to provide isolation.

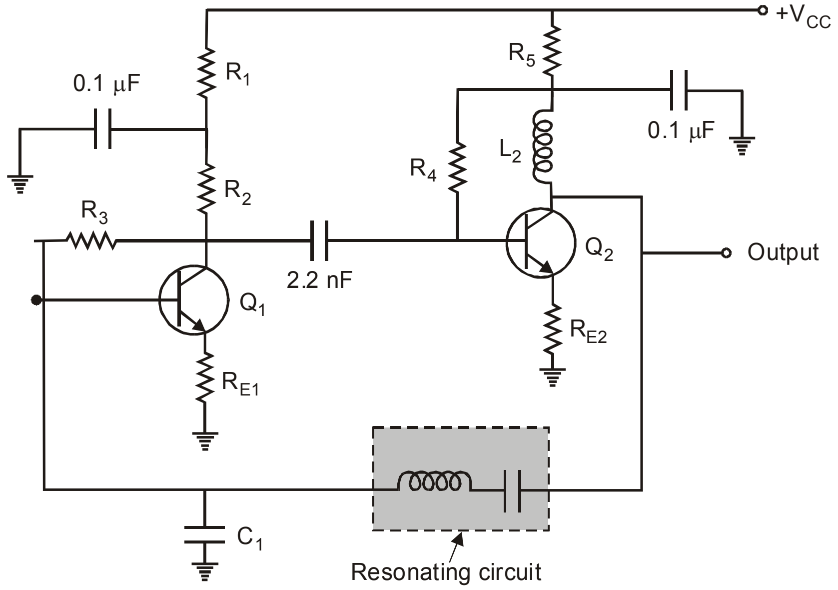


Figure 2.24: Series Resonating circuit for Franklin Oscillator

The frequency of oscillation is expressed as follows

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \qquad \text{... (2.24)}$$

2.9.4 Salient features of Franklin Oscillator

1. The salient feature of the Franklin oscillator is that the tremendous amplification enables operation with very small coupling to the resonant circuit. Therefore, the frequency is relatively little influenced by changes in the active device.
2. Q factor of the resonant circuit is substantially free from degradation.
3. The closest approach to the high-frequency stability inherent in this oscillator is attained by restriction of operation to, or near to, the Class-A region.

2.9.5 Advantages of Franklin Oscillator

It maintaining circuit need be only very loosely coupled to, and impose very light loading of the resonant circuit.

2.9.6 Applications of Franklin Oscillator

1. RF Oscillator.
2. Used in precision frequency meters and frequency measurement.
3. Used in Application circuits and Laboratory devices.

2.10 ARMSTRONG OSCILLATOR

The Armstrong oscillator was invented in 1912 and is named after its **inventor, Edwin Armstrong.**

This is also a type of LC feedback oscillator which uses transformer coupling to feed back a portion of the signal voltage, as shown in Figure 2.25.

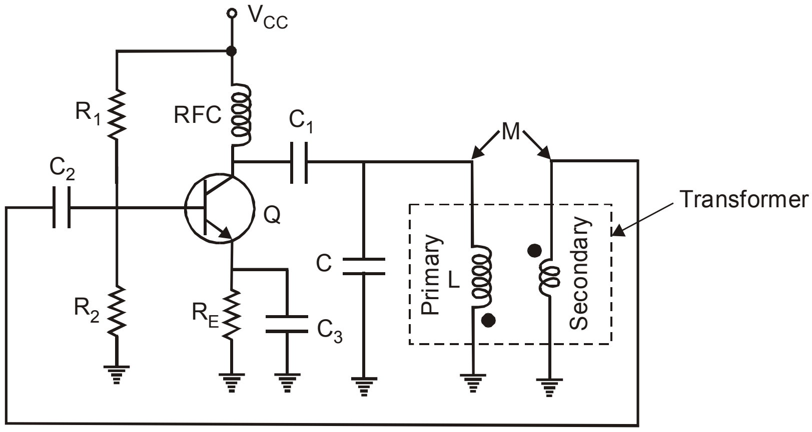


Figure 2.25: Armstrong Oscillator

The transformer secondary coil provides the feedback to keep the oscillation going. This oscillator is also called *"tickler"* oscillator because of the secondary coil is as feedback and secondary winding is called tickler coil.

2.10.1 Operation of Armstrong Oscillator

The C_1 and C_2 are coupling capacitors. LC tank circuit is driven by collector of transistor Q. The feedback signal is taken from the small secondary winding and feedback to the base of transistor Q. There is a phase shift of 180° in the transformer. Mutual inductance between primary and secondary of transformer also provides another 180° phase shift. So overall phase shift is 360° or 0°.

Ignoring the loading effect of the base, the feedback fraction is

$$\text{Feedback fraction} \quad \beta = \frac{M}{L} \qquad \text{... (2.25)}$$

where M – Mutual Inductance

L – Inductance of the primary winding

For starting of oscillations, the voltage gain must be greater than $\frac{1}{\beta}$

$$A > \frac{1}{\beta} > \frac{L}{M} \qquad \text{... (2.26)}$$

The **frequency of sustained oscillation**,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \qquad \text{... (2.27)}$$

The frequency of oscillation is set by the inductance of the primary winding in parallel with inductance and capacitance.

2.10.2 Advantages of Armstrong Oscillator

Its frequency is fairly stable, and the output amplitude is relatively constant.

2.10.3 Disadvantage of Armstrong Oscillator

The Armstrong is less common than the Colpitts, Clapp, and Hartley, mainly because of the disadvantage of transformer size and cost.

2.10.4 Applications of Armstrong Oscillator

1. The Armstrong oscillator is used to produce a sine-wave output of constant amplitude and of fairly constant frequency within the radio frequency range.
2. It is generally used as a local oscillator in receivers, as a source in signal generators, and as a radio-frequency oscillator in the medium and high frequency range.

2.11 TUNED COLLECTOR OSCILLATOR

Tuned collector oscillation is a type of transistor LC oscillator where the tuned circuit (tank) consists of a transformer and a capacitor is connected in the collector circuit of the transistor. The tuned circuit connected at the collector circuit behaves like a purely resistive load at resonance and determines the oscillator frequency.

2.11.1 Construction of Tuned collector oscillator

In the circuit diagram resistor R_1 and R_2 forms a voltage divider bias for the transistor. R_e is the emitter resistor which is meant for thermal stability. It also limits the collector current of the transistor. C_e is the emitter by-pass capacitor used to by-pass the amplified oscillations. If C_e is not there, the amplified AC oscillations will drop across R_e and will add on to the base-emitter voltage (V_{be}) of the transistor and this will alter the DC biasing conditions. C_2 is the by-pass capacitor for resistor R_2.

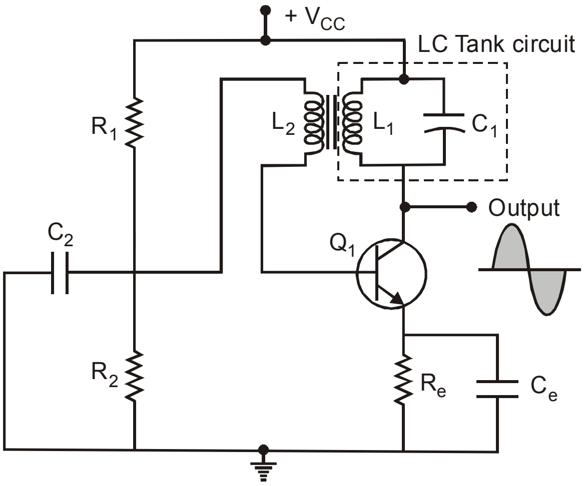


Figure 2.26: Tuned Collector Oscillator

2.11.2 Operation of tuned Collector Oscillator

The oscillations produced in the tank circuit is fed back to the base of transistor Q_1 by the secondary coil by inductive coupling. The amount of feedback can be adjusted by varying the turns ratio of the transformer. The winding direction of the secondary coil (L_2) is in such a way that the voltage across it will be 180° phase opposite to that of the voltage across primary (L_1). Thus the feedback circuit produces a phase shift of 180° and the transistor alone produces a phase shift of another 180°. As a result a total phase shift of 360° is obtained between input and output and it is a very necessary condition for positive feedback and sustained oscillations. The collector current of the transistor compensates the energy lost in the tank circuit. This is done by taking a small amount of voltage from the tank circuit, amplifying it and applying it back to the tank circuit. Capacitor C_1 can be made variable in variable frequency applications.

The **Frequency of sustained oscillations**, f_r is:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hertz} \qquad \text{... (2.28)}$$

2.11.3 Applications of Tuned Collector Oscillator

The common applications of tuned collector oscillator are RF oscillator circuits, mixers, frequency demodulators, signal generators etc.

2.12 RC PHASE SHIFT

RC phase shift oscillator consists of an amplifier and feedback network consisting of Resistors and capacitors arranged in ladder manner. Hence it is called as *RC ladder type oscillator.*

RC Feedback Network

In an **RC Oscillator** circuit the input is shifted 180° through the amplifier stage and 180° again through a second inverting stage giving "180° + 180° = 360°" of phase shift which is effectively the same as 0° thereby giving us the required positive feedback. In other words, the phase shift of the feedback loop should be 0°.

In a **Resistance-Capacitance Oscillator** or simply an **RC Oscillator**, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same network by using RC elements in the feedback branch.

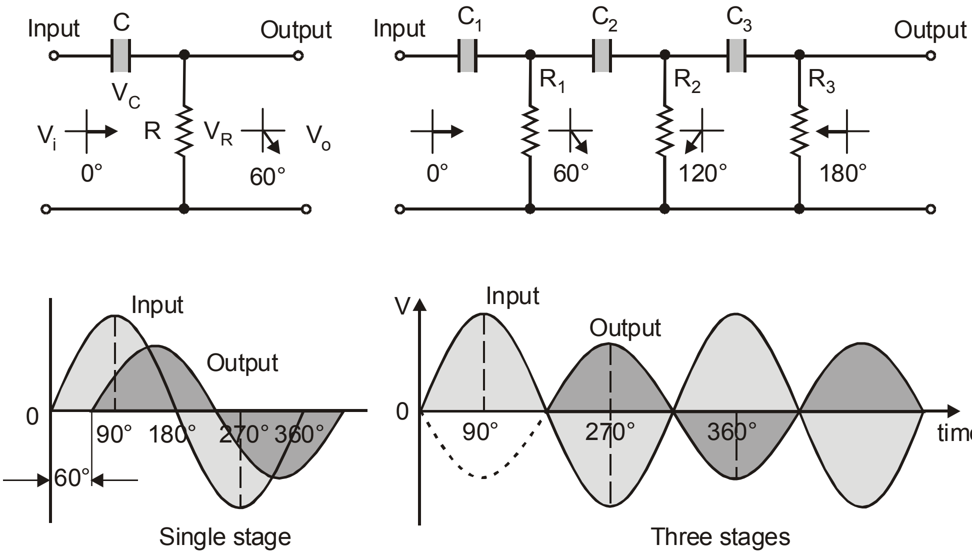


Figure 2.27: Basic RC Phase shift concepts

The circuit on the left shows a single Resistor-Capacitor Network whose output voltage "leads" the input voltage by some angle less than 90°. An ideal single-pole RC circuit would produce a phase shift of exactly 90°, and because 180° of phase shift is required for oscillation, at least two single-poles must be used in an RC **oscillator** design.

However in reality it is difficult to obtain exactly 90° of phase shift so more stages are used.

The capacitor C and resistance R are in series.

Now X_C is the capacitive reactance; $X_C = \frac{1}{2\pi fC}$ Ohm

Total Impedence of the circuit is

$$Z = R - jX_C \Rightarrow R - j\left(\frac{1}{2\pi fC}\right) \Rightarrow |Z| = \sqrt{R^2 + (X_C)^2} \text{ Ohm}$$

The voltage across Resistance is $V_R = IR$

The voltage across Capacitor is $V_C = IX_C$

The amount of actual phase shift in the circuit depends upon the values of R and C and the chosen frequency of oscillations with the phase angle (Φ).

$$\varphi = \tan^{-1}\left(\frac{X_C}{R}\right)$$

In figure 2.28, the values of R and C have been chosen so that at the required frequency the output voltage leads the input voltage by an angle of about 60°. Then the phase angle between each successive RC section increases by another 60° giving a phase difference between the input and output of 180° (3 × 60°) as shown in figure 2.28.

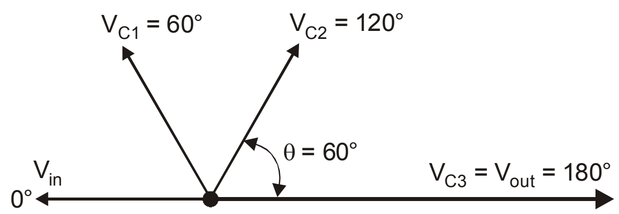


Figure 2.28: Vector diagram of phase difference

Then by connecting together three such RC networks in series we can produce a total phase shift in the circuit of 180° at the chosen frequency and this forms the bases of a "phase shift oscillator" otherwise known as a **RC Oscillator** circuit.

2.12.1 RC Phase shift using Transistor

Here voltage series feedback is employed with the resistance network will be shunted by low 'R' of transistor.

It uses common emitter single stage amplifier and a phase shifting network consists of 3 identical RC networks. In this oscillator, the required phase shift of 180° is obtained by using RC network. In practice R of last section is adjusted in such a way that the total phase produced by Cascade connection of RC network is exactly equal to 180°. The transistor in the amplifier circuit gives a phase shift of another 180°. Hence total phase shift around the circuit is 360° or 0°. A phase shift network is a feedback network, so the output of amplifier is given as input to feedback network.

Design Analysis

From figure 2.29, we know that the value of $R_3 = R - R_i$

Where $R_i = h_{ie}$, Input resistance of transisor

The 3 RC section of phase shifting network are identical, R_1 R_2 and R_e are biasing resistors.

$$R = R_3 + R_i$$

where $R_i = h_{ie} \parallel R_1 \parallel R_2.$

When considering R_1 and R_2,

Feedback current $X_f = -I_3$

Input current $X_i = I_b$

$$\text{Loop current gain } \frac{-X_f}{X_i} = \frac{I_3}{I_b} \qquad \text{... (2.29)}$$

Derivation of Frequency of Oscillation

Replacing the transistor by h-parameter model, then the equivalent circuit becomes,

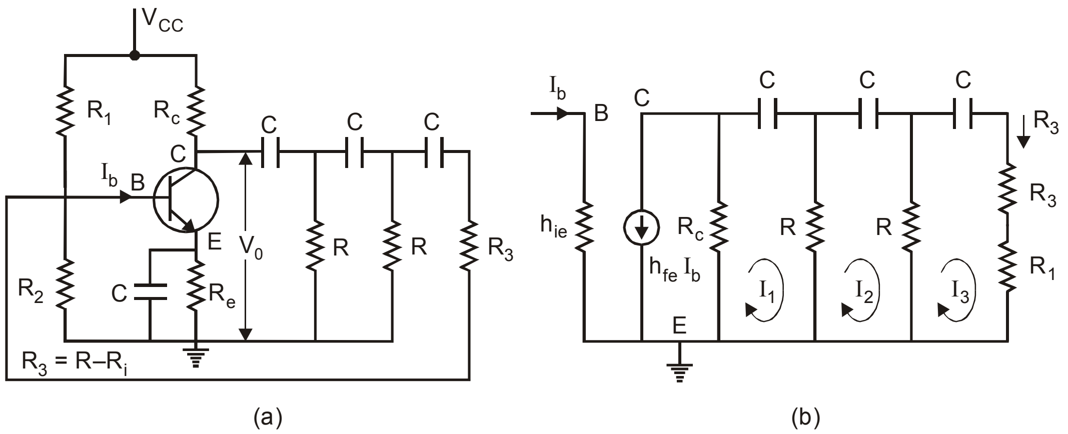


Figure 2.29: (a) RC phase shift using Transistor; (b) Equivalent circuit

Apply KVL to figure 2.30,

For Loop 1: $\left(R_C + R - \dfrac{j}{\omega C}\right) I_1 - R\, I_2 = -h_{fe} I_b R_C$

For Loop 2: $-R\, I_1 + \left(2R - \dfrac{j}{\omega C}\right) I_2 - R\, I_3 = 0$

For Loop 3: $-R\, I_2 + \left(2R - \dfrac{j}{\omega C}\right) I_3 = 0$

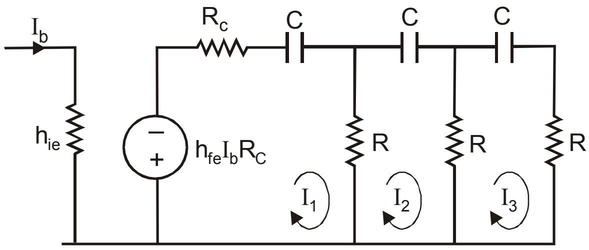


Figure 2.30: Equivalent circuit

By taking 'R' as common, the modified equations are

$$\left(\frac{R_C}{R} + 1 - \frac{j}{\omega RC}\right) I_i - I_2 = -h_{fe} \frac{R_C}{R} I_b$$

$$-I_1 + \left(2 - \frac{j}{\omega RC}\right) I_2 - I_3 = 0$$

$$-I_2 + \left(R - \frac{j}{\omega RC}\right) I_3 = 0$$

Let $\dfrac{R_C}{R} = K$ and $\alpha = \dfrac{1}{\omega RC}$, the equations becomes,

$$(1 + K - j\alpha)\, I_1 - I_2 = -h_{fe}\, I_b\, K$$

$$-I_1 + (2 - j\alpha)\, I_2 - I_3 = 0$$

$$-I_2 + (2 - j\alpha)\, I_3 = 0$$

Using Gamer's Rule,

$$\begin{bmatrix} 1+K-j\alpha & -1 & 0 \\ -1 & 2-j\alpha & -1 \\ 0 & -1 & 2-j\alpha \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} -h_{fe} I_b K \\ 0 \\ 0 \end{bmatrix}$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{1}{\Delta} \begin{vmatrix} 1-K-j\alpha & -1 & -h_{fe} I_b K \\ -1 & 2-j\alpha & 1 \\ 0 & -1 & 0 \end{vmatrix} = \frac{1}{\Delta}\left[-h_{fe} I_b K\right]$$

$$\begin{aligned} \Delta &= [1 + K - j\alpha]\,[(2 - j\alpha)^2 - 1] + 1\,[-(2 - j\alpha)] \\ &= [1 + K - j\alpha]\,[4 - \alpha^2 - j4\alpha - 1] - 2 - j\alpha \\ &= 4 - \alpha^2 - j4\alpha - 1 + 4K - \alpha^2 K - j4K\alpha - K - j4\alpha + j\alpha^3 - 4\alpha^2 + j\alpha - 2 + j\alpha \\ &= j\alpha^3 - 5\alpha^2 - \alpha^2 K - j4K\alpha + 3K - 6j\alpha + 1 \\ &= -(5 + K)\alpha^2 + 3K + 1 + j[\alpha^3 - (6 + 4K)\,\alpha] \end{aligned}$$

Since $\quad I_3 = \frac{1}{\Delta}\left[-h_{fe} I_b K\right]$

Then
$$I_3 = \frac{-h_{fe} I_b K}{-(5+K)\alpha^2 + 3K + 1 + j\left[\alpha^3 - (6+4K)\alpha\right]} \qquad \text{... (2.30)}$$

where I_3 = Output current of feedback circuit

I_b = Input current of Amplifier

I_c = h_{fe} I_b – Input current of feedback Amplifier

$$\beta = \frac{\text{Output of feedback circuit}}{\text{Input of feedback circuit}} = \frac{I_3}{h_{fe} I_b}$$

$$A = \frac{\text{Output of Amplifier circuit}}{\text{Input of Amplifier circuit}} = \frac{I_3}{I_b} = h_{fe}$$

Equation (2.30) becomes,

$$\because \frac{I_3}{I_b} = \frac{-h_{fe} K}{-(5+K)\alpha^2 + 3K + 1 + j\left[\alpha^3 - (6+4K)\alpha\right]} \qquad \text{... (2.31)}$$

The Barkhausen condition for the loop gain $\frac{I_3}{I_b}$ phase shift must equal to zero.

The phase shift equals zero provided by imaginary part is zero. Hence taking imaginary part from equation (2.31),

$$\alpha^3 = (6 + 4K)\alpha \qquad \text{... (2.32)}$$

$$\alpha^2 = 6 + 4K$$

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

Since $$\alpha = \frac{1}{\omega RC}; \quad \frac{1}{\omega RC} = \sqrt{6 + 4K}$$

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

$$f = \frac{1}{2\pi RC\sqrt{6 + 4K}} \qquad \text{... (2.33)}$$

For maintaining sustained oscillation at above frequency, $|I_3|I_b| > 1$,

$$\left|\frac{I_3}{I_b}\right| = \left|\frac{-h_{fe}K}{-(5 + K)(6 + 4K) + 3K + 1}\right| > 1$$

Above equation is obtained by considering only real part of equation (2.31) and substitute equation (2.32),

$$|-h_{fe}\,K| > |-(5 + K)(6 + 4K) + 3K + 1|$$

$$|-h_{fe}\,K| > |-30 - 26K - 4K^2 + 3K + 1|$$

$$|-h_{fe}\,K| > |-4K^2 - 23K - 29|$$

$$h_{fe}\,K > 4K + 23 + \frac{29}{K} \qquad \text{... (2.34)}$$

To *determine the minimum value of h_{fe}*. The optimum value of K should be determined by differentiating h_{fe} with respect to K and equate it to zero.

$$\frac{dh_{fe}}{dK} > \frac{d}{dK}\left(4K + 23 + \frac{29}{K}\right)$$

$$0 > 4 - \frac{29}{K^2}$$

$$\therefore \quad K^2 < \frac{29}{4} \qquad \therefore \quad \boxed{K < 2.7}$$

Substitute the optimum value K = 2.7 in equation (2.34),

$$h_{fe} > 4 \times 2.7 + 23 + \frac{29}{2.7}$$

$$\therefore \quad h_{fe} > 44.5 \text{ or } (h_{fe})_{min} = 44.5$$

The BJT with a small signal CE short circuit gain $h_{fe} < 44.5$ cannot be used in this phase shift oscillator.

By changing the values of R and C, the frequency of oscillator can be changed.

No. of RC Network	*Phase Shift per Network*	*Total Phase shift*	*Stability*
3	60°	3 × 60° = 180°	Good
4	45°	3 × 45° = 180°	Improved
2	90°	2 × 90° = 180°	Not possible for practical impossible

2.12.2 RC Phase shift using OP-AMP

As the feedback is connected to the non-inverting input, the operational amplifier is therefore connected in its "inverting amplifier" configuration which produces the required 180° phase shift while the RC network produces the other 180° phase shift at the required frequency (180° + 180°).

The feedback network consists of 3 identical RC stages. Each of the RC stage provides a 60° phase shift so that the total phase shift due to feedback network is 180°.

Applying KVL to each loop of figure 2.31,

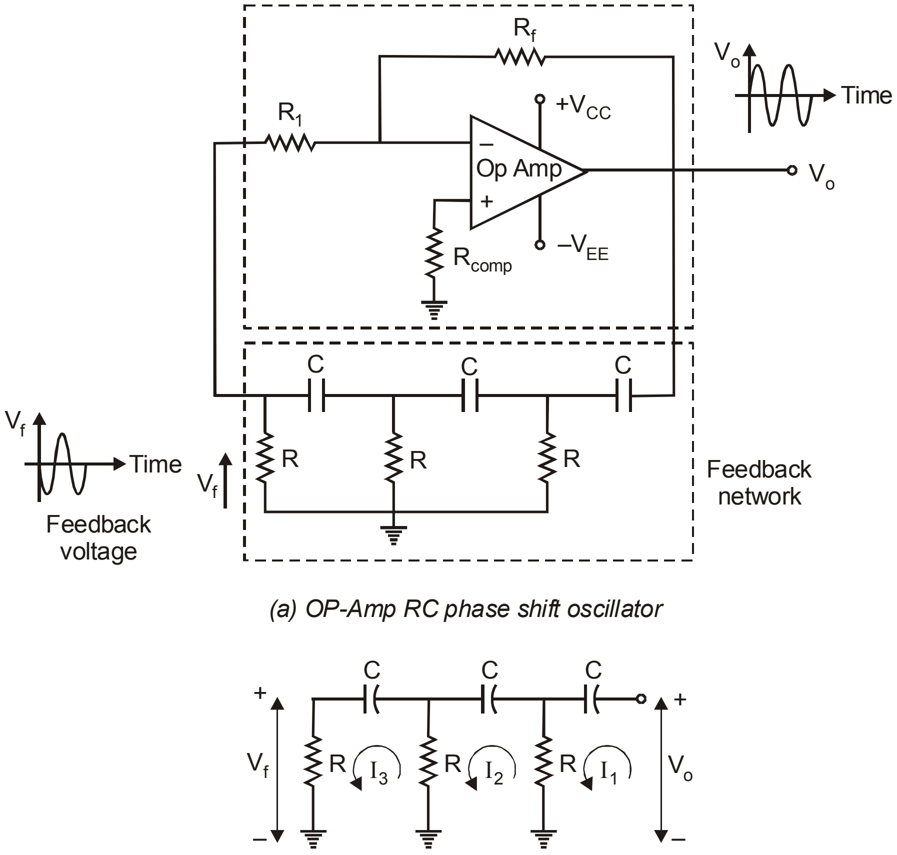
Loop 1: $I_1\left(R - \frac{j}{\omega C}\right) - I_2 R = V_o$

Loop 2: $-I_1 R + I_2\left(2R - \frac{j}{\omega C}\right) - I_3 R = 0$

Loop 3: $0 - I_2 R + I_3\left(2R - \frac{j}{\omega C}\right) = 0$ and $V_f = I_3 R$

By taking 'R' as common, the modified equations are

$$I_1\left(1 - \frac{j}{\omega C}\right) - I_2 = \frac{V_o}{R}$$



(a) OP-Amp RC phase shift oscillator

(b) Calculating β from phase shift network

Figure 2.31

$$-I_1 + I_2\left(2 - \frac{j}{\omega RC}\right) - I_3 = 0$$

$$-I_2 + I_3\left(2 - \frac{j}{\omega RC}\right) = 0$$

Let $\alpha = \dfrac{j}{\omega RC}$, the modified equation becomes,

$$I_1(1 - j\alpha) - I_2 = \frac{V_o}{R}$$

$$-I_1 + I_2(2 - j\alpha) - I_3 = 0$$

$$-I_2 + I_3(2 - j\alpha) = 0$$

Writing this in matrix form, we get,

$$\begin{bmatrix} 1-j\alpha & -1 & 0 \\ -1 & 2-j\alpha & -1 \\ 0 & -1 & 2-j\alpha \end{bmatrix}\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} \frac{V_o}{R} \\ 0 \\ 0 \end{bmatrix}$$

Using Gamer's Rule,

$$\Delta = (1 - j\alpha)\{(2 - j\alpha)^2 - 1\} + 1\{-1\ (2 - j\alpha)\}$$

$$= (1 - j\alpha)\{4 - \alpha^2 - 4j\alpha - 1\} - 2 + j\alpha$$

$$= (1 - j\alpha)\{3 - \alpha^2 - 4j\alpha\} - 2 + j\alpha$$

$$= 3 - \alpha^2 - 4j\alpha - 3j\alpha + j\alpha^3 - 4\alpha^2 - 2 + j\alpha$$

$$= j\alpha^3 - \alpha^2 - 4\alpha^2 - 4j\alpha - 3j\alpha + j\alpha + 3 - 2$$

$$\Delta = j\alpha^3 - 5\alpha^2 - 6j\alpha + 1$$

Since $I_3 = \frac{\Delta_3}{\Delta}$,

Then

$$\Delta_3 = \begin{bmatrix} 1-j\alpha & -1 & \frac{V_o}{R} \\ -1 & 2-j\alpha & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

$$\Delta_3 = \frac{V_o}{R}$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{\frac{V_o}{R}}{j\alpha^3 - 5\alpha^2 - 6j\alpha + 1}$$

$$V_i = V_f = I_3 R = \frac{V_0}{j\alpha^3 - 5\alpha^2 - 6j\alpha + 1}$$

Since, $\beta = \frac{V_f}{V_o}$ Then,

$$\beta = \frac{V_f}{V_o} = \frac{1}{j\alpha^3 - 6j\alpha - 5\alpha^2 + 1}$$

$$= \frac{1}{j\alpha\left(\alpha^2 - 6\right) - 5\alpha^2 + 1} \quad \text{... (2.35)}$$

Frequency of Oscillation

To have phase shift of 180°, Imaginary part of denominator must be zero,

$$\alpha(\alpha^2 - 6) = 0$$

$$\alpha^2 - 6 = 0 \Rightarrow \alpha^2 = 6$$

$$\boxed{\alpha = \sqrt{6}}$$

Since $\alpha = \dfrac{j}{\omega RC} \Rightarrow \sqrt{6} = \dfrac{j}{\omega RC}$

We know that $\omega = 2\pi f$, so $\sqrt{6} = \dfrac{1}{2\pi f\, RC}$

$$\text{Frequency of oscillation} \quad f = \frac{1}{2\pi RC\sqrt{6}} \qquad \text{... (2.36)}$$

At this frequency circuit oscillates,

Then $\quad \beta = \dfrac{1}{j\alpha(6-6) - 5(6) + 1} \Rightarrow |\beta| = -\dfrac{1}{29}$

Negative sign indicates phase shift of 180°.

To have oscillations, $|AB| \geq 1$,

$$\therefore \quad |A|\ |B| > 1$$

$$|A| \geq \frac{1}{|\beta|} \geq \frac{1}{\left(\frac{1}{29}\right)}$$

$$|A| \geq 29$$

The gain of the inverting OP-AMP should be atleast 2, or $R_f = 29\ R_1$. The gain A_V is kept greater than 29 to ensure that variations in circuit parameters will not make $|A_V\beta| < 1$. Otherwise oscillations will die out.

2.12.3 RC Phase shift using FET

FET amplifier is followed by three cascaded arrangements of a capacitor C, resistor R as shown in figure 2.32. The output of the last RC combination is returned to the gate. This forms the feedback connection. The FET amplifier shifts the phase of voltage appearing at the gate by 180°. The RC network shifts the phase by additional amount. At some frequency, the phase-shift introduced by this network will be exactly 180°. The total phase-shift at this frequency, from the gate around the circuit and back to the gate is +180 –180 = 0°. At this particular frequency, the circuit will oscillate.

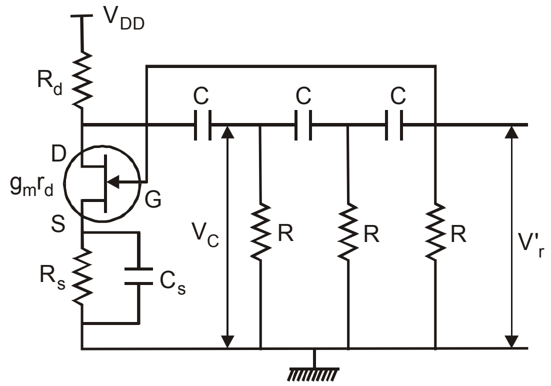


Figure 2.32: JFET RC Phase Shift Oscillator

For FET amplifier, Gain is $|A| = g_m R_L$ where $R_L = \dfrac{R_L r_d}{R_L + r_d}$

Feedback network gain $\beta = \dfrac{V_f}{V_\beta} = \dfrac{1}{1 - 5\alpha^2 - j\left(6\alpha - \alpha^3\right)}$

where $\alpha = \dfrac{j}{\omega R_C}$, phase shift of $\dfrac{V_f}{V_\beta} = 180°$

Considering imaginary part $j(6\alpha - \alpha^3) = 0 \Rightarrow \boxed{\alpha^2 = 6}$

$$\because \quad \alpha^2 = \frac{j}{\omega^2 R^2 C^2}, \text{ then } 6 = \frac{j}{\omega^2 R^2 C^2}$$

$$\because \quad \boxed{f = \frac{1}{2\pi R_C \sqrt{6}}} \qquad \text{... (2.37)}$$

$$|\beta| = \frac{1}{29} \quad \text{and} \quad |A| \geq 29$$

2.12.4 Advantages of RC Oscillators

1. It provides good frequency stability.
2. The phase shift oscillator circuit is much simpler than the Wien bridge oscillator circuit because it does not need negative feedback and the stabilization arrangements.
3. The output is sinusoidal that is quite distortion free.
4. They have a wide frequency range (from a few Hz to several hundred kHz).
5. **RC Oscillators** are stable and provide a well-shaped sine wave output with the frequency being proportional to 1/RC and therefore, a wider frequency range is possible when using a variable capacitor.
6. RC phase shift oscillator is used to generate frequency in audio range and it is a fixed audio frequency oscillator.

2.12.5 Disadvantages of RC phase shift oscillator

1. The output is small. It is due to smaller feedback.
2. It is difficult for the circuit to start oscillations as the feedback is usually small.
3. The frequency stability is not as good as that of Wien bridge oscillator.
4. It needs high voltage (12V) battery so as to develop sufficiently large feedback voltage.
5. RC Oscillators are restricted to frequency applications because of their bandwidth limitations to produce the desired phase shift at high frequencies.

2.12.6 Applications of RC Phase shift oscillator

1. FET phase-shift oscillator is used for generating signals over a wide frequency range.
2. RC phase shift oscillators are used for musical instruments, voice synthesis, and GPS units. They work at all audio frequencies.

2.13 WIEN BRIDGE OSCILLATOR

The Wien bridge oscillator uses positive feedback to get a phase shift on an RC filter. Generally, in oscillator, amplifier stage introduces 180° phase shift and feedback network introduces additional 180° phase shift, so total phase shift is 360°. This is necessary condition for oscillator. In wien bridge oscillator uses non-inverting amplifier so it does not provide any phase shift during amplifier stage.

Basic Wien Bridge circuit

Output of amplifier is applied between the terminals A and C, which is input to feedback network. The Amplifier input is supplied from terminals B and D which is output from feedback network as shown in figure 2.33.

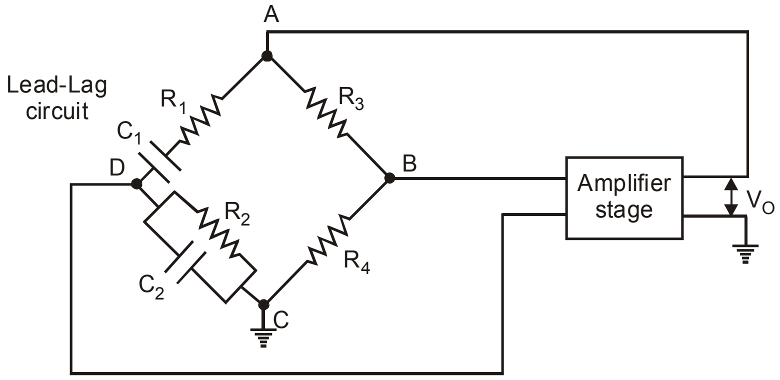


Figure 2.33: Basic Wienbridge Oscillator Circuit

The typical Wien bridge consists of three parts.

1. An RC circuit that causes a lead and lag property (R_1–C_1 and R_2–C_2).
2. A voltage divider (R_3-R_4).

The operation of this lead-lag circuit is as follows.

- At lower frequencies, the lead circuit takes over due to the high reactance of C_1.
- As the frequency increases, X_{C1} decreases, thus allowing the output voltage to increase.
- At some specified frequency, the response of the lag circuit takes over, and the decreasing value of X_{C1} causes the output voltage to decrease.

2.13.1 Analysis of basic Wienbridge Oscillator Circuit

Figure 2.34 shows feedback network of Wienbridge oscillator,

Let $$Z_1 = R_1 + \frac{1}{j\omega C_1} \Rightarrow R_1 - \frac{j}{\omega C_1} = \frac{1 + j\omega R_1 C_1}{j\omega C_1} \quad \text{... (2.38a)}$$

$$Z_2 = R_2 \,||\, \frac{1}{j\omega C_2} \Rightarrow \frac{R_2 \times \frac{-j}{\omega C_2}}{R_2 - \frac{j}{\omega C_2}} \Rightarrow \frac{R_2}{1 + j\omega R_2 C_2} \quad \text{... (2.38b)}$$

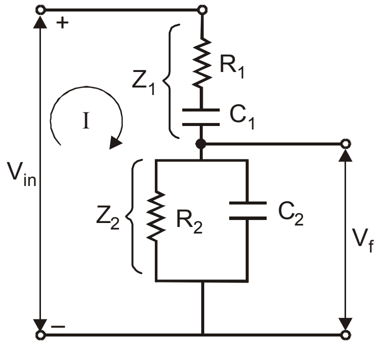


Figure 2.34: Feedback network of Wienbridge Oscillator

Voltage across $V_f = IZ_2$

where $I = \dfrac{V_{in}}{Z_1 + Z_2}$

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

Since $\beta = \dfrac{V_f}{V_{in}} \Rightarrow \dfrac{Z_2}{Z_1 + Z_2}$ ... (2.39)

Substituting equations (2.38a) and (2.38b) in equation 2.39,

$$\beta = \frac{\dfrac{R_2}{1 + j\omega R_2 C_2}}{\dfrac{1 + j\omega R_1 C_1}{j\omega C_1} + \dfrac{R_2}{1 + j\omega R_2 C_2}} \Rightarrow \frac{\dfrac{R_2}{1 + sR_2C_2}}{\dfrac{1 + sR_1C_1}{sC_1} + \dfrac{R_2}{1 + sR_2C_2}} \quad [\text{since } s = j\omega]$$

$$= \frac{\dfrac{R_2}{(1 + sR_2C_2)}}{\dfrac{\left[(1 + sR_1C_1)(1 + sR_2C_2) + sR_2C_1\right]}{(1 + sR_2C_2)(sC_1)}}$$

$$= \frac{sR_2C_1}{(1 + sR_1C_1)(1 + sR_2C_2) + sR_2C_1}$$

$$= \frac{sR_2C_1}{1 + sR_2C_2 + sR_1C_1 + s^2R_2R_1C_1C_2 + sR_2C_1}$$

$$= \frac{sR_2C_1}{1 + s(R_1C_1 + R_2C_2 + R_2C_1) + s^2R_1R_2C_1C_2}$$

Substituting $s = j\omega$ and $s^2 = j^2\omega^2$ so $s^2 = -\omega^2$

$$\beta = \frac{j\omega R_2C_1}{1 + j\omega\left(R_1C_1 + R_2C_2 + C_1R_2\right) - \omega^2\left(R_1R_2C_1C_2\right)}$$

$$= \frac{j\omega R_2C_1}{\left(1 - \omega^2R_1R_2C_1C_2\right) + j\omega\left(R_1C_1 + R_2C_2 + C_1R_2\right)} \qquad \text{... (2.40)}$$

Frequency of Oscillation

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

$$1 - \omega^2R_1R_2C_1C_2 = 0$$

$$\omega^2R_1R_2C_1C_2 = 1$$

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

Since $\omega = 2\pi f$,

$$\boxed{f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}} \qquad \text{... (2.41)}$$

For practical consideration,

$$R_1 = R_2 = R_1 \text{ and } C_1 = C_2 = C$$

Then $$f = \frac{1}{2\pi\sqrt{R^2C^2}} \Rightarrow \frac{1}{2\pi RC}$$ For $R_1 = R_2 = R$ and $C_1 = C_2 = C$

Equation (2.40) becomes

$$\beta = \frac{j\omega RC}{\left(1 - \omega^2R^2C^2\right) + j\omega\left(RC + RC + RC\right)}$$

$$= \frac{j\omega RC}{\left(1 - \omega^2R^2C^2\right) + 3j\omega\left(RC\right)}$$

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

$$\beta = \frac{j\omega RC}{3j\omega RC} \qquad \therefore \boxed{\beta = \frac{1}{3}}$$

Note: Positive sign indicates that phase shift by feedback network is 0°.

For sustained oscillations

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

$$|A| \geq \frac{1}{|\beta|} \quad a \quad |A| \geq \frac{1}{\left(\frac{1}{3}\right)}$$

$$|A| \geq 3$$

If the gain $|A| \geq 3$, sometimes oscillations keep growing and it may clip the output sinewave. It can be eliminated by adaptive negative feedback.

If $R_1 \neq R_2$ and $C_1 \neq C_2$, then,

$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

2.13.2 Wien bridge Oscillator using Transistor

It is essentially a two-stage amplifier with an R-C bridge circuit. R-C bridge circuit (Wien bridge) is a lead-lag network. In the bridge circuit R_1 in series with C_1, R_3, R_4 and R_2 in parallel with C_2 form the four arms.

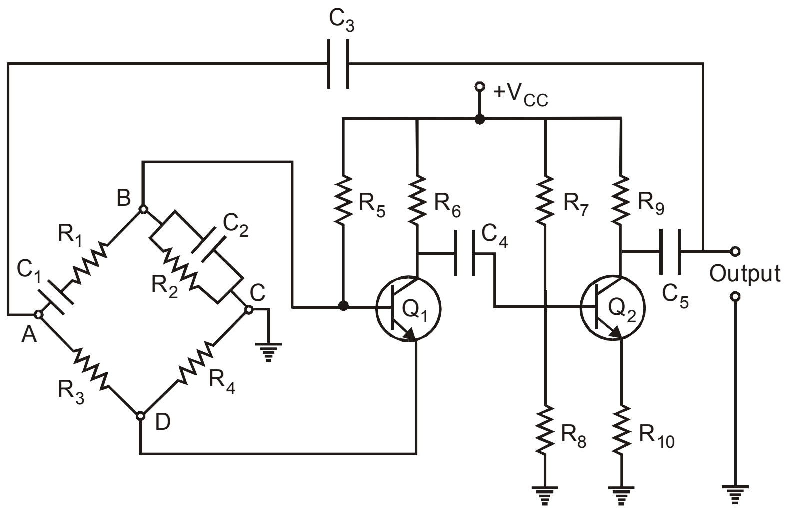


Figure 2.35: Wien Bridge Oscillator using Transistor

This bridge circuit can be used as feedback network for an oscillator, provided that the phase shift through the amplifier is zero. This requisite condition is achieved by using a two stage amplifier, as illustrated in the figure. In this arrangement the output of the second stage is supplied back to the feedback network and the voltage across the parallel combination C_2 R_2

is fed to the input of the first stage. Transistor Q_1 serves as an oscillator and amplifier whereas the transistor Q_2 as an inverter to cause a phase shift of 180°. The circuit uses positive and negative feedbacks.

The positive feedback is through R_1 C_1 R_2, C_2 to transistor Q_1 and negative feedback is through the voltage divider to the input of transistor Q_1. Resistors R_3 and R_4 are used to stabilize the amplitude of the output.

The two transistors Q_1 and Q_2 thus cause a total phase shift of 360° and ensure proper positive feedback. The negative feedback is provided in the circuit to ensure constant output over a range of frequencies.

This is achieved by taking resistor R_4 in the form of a temperature sensitive lamp, whose resistance increases with the increase in current. In case the amplitude of the output tends to increase, more current would provide more negative feedback. Thus the output would regain its original value. A reverse action would take place in case the output tends to fall.

2.13.3 Wien bridge oscillator using OPAMP

In Wien-bridge oscillator using OPAMP, feedback signal in the circuit is connected to non-inverting amplifier input terminal so that the opamp is working as non-inverting amplifier. Therefore, the feedback network need not provide any phase shift. The condition of zero phase shift around the circuit is achieved by balancing the bridge.

The output of AC signal of OPAMP amplifier is fed back to point A of the bridge. The feedback signal V_f across the parallel combination of R_2C_2 is applied to non-inverting input terminal of OPAMP.

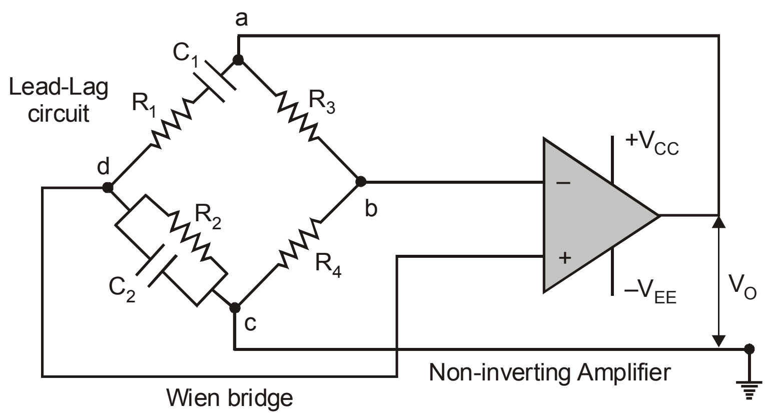


Figure 2.36: Wien Bridge oscillator using OPAMP

$$A = \frac{R_3 + R_4}{R_4} = \frac{R_3}{R_4} + 1$$

The amplifier voltage gain,

Since $R_3 = 2R_4$, Then $A = \frac{2R_4}{R_4} + 1 = 3$

The above corresponds with the feedback network attenuation of 1/3. Thus, in this case, voltage gain A, must be equal to or greater than 3, to sustain oscillations. i.e, $A \geq 3$.

To have a voltage gain of 3 is not difficult. On the other hand, to have a gain as low as 3 may be difficult. For this reason also negative feedback is essential.

The **frequency of sustained oscillation**, f_r is:

$$f_r = \frac{1}{2\pi RC} \text{ Hertz}$$

Advantages of wienbridge oscillator

1. The frequency range can be selected simply by using decade resistance boxes.
2. The frequency of oscillation can be easily varied just by changing RC network.
3. Provides a stable low distortion sinusoidal output over a wide range of frequency.
4. High gain due to two-stage amplifier.
5. Stability is high.

Disadvantages of wienbridge oscillator

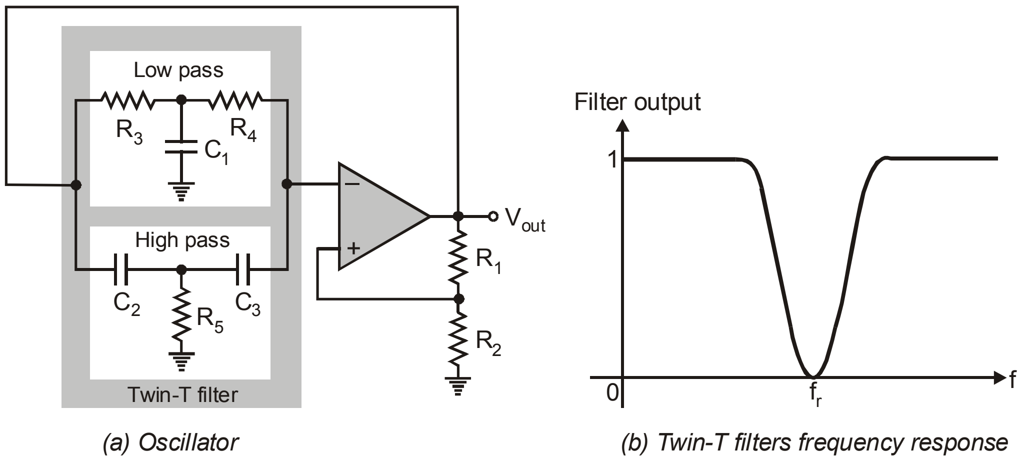
1. The circuit needs two transistors and a large number of other components.
2. The maximum frequency output is limited because of amplitude and the phase-shift characteristics of amplifier.
3. The main disadvantage of the Wien-bridge oscillator is that a high frequency of oscillation cannot be generated.

Application of wienbridge oscillator

It is used for measurement of audio frequency.

2.14 TWIN-T OSCILLATOR

Another type of RC feedback oscillator is called the **twin-T** because of the two T-type RC filters used in the feedback loop which is used as *notch filter*. One of the twin-T filters has a low-pass response, and the other has a high-pass response.



(a) Oscillator (b) Twin-T filters frequency response

Figure 2.37: Twin-T oscillator

- The combined parallel filters produce a band-stop response with a center frequency equal to the desired frequency of oscillation f_r, as shown in figure 2.37.

2.14.1 Operation of Twin- T Oscillator

Positive feedback to the noninverting input is given through potential divider. Negative feedback is given to inverting input through Twin-T filter.

When the power is switched ON, the resistance R_2 is low and positive feedback is maximum which builds oscillation.

As oscillations grow, the resistance R_2 increases, thus decreasing the positive feedback which controls the growing oscillations and makes them as sustained oscillations.

- Oscillation cannot occur at frequencies above or below f_r because of the negative feedback through the filters.
- At f_r however, there is negligible negative feedback; thus, the positive feedback through the voltage divider (R_1 and R_2) allows the circuit to oscillate.
- At $f = f_r$. Its phase angle is 0 so it does not introduce any phase shift. Its gain is 1 at low and high frequencies but at $f = f_r$ the gain reduces to zero since it acts like notch filter as it notches out frequencies near f_r.
- The frequency of oscillations is $f_r = \frac{1}{2\pi\sqrt{LC}}$ Hertz

Advantages of Twin-T Oscillator

1. It yields better frequency stability.
2. Has flexible to adjust the frequency of oscillations over wide range.

Disadvantages of Twin-T Oscillator

1. It is operated only at one frequency so this oscillator is not used rarely.

2.15 FREQUENCY RANGE OF RC AND LC OSCILLATORS

Frequency range	*Oscillator type*	*Oscillator*	*Uses*	*Significance*
5 Hz to 1 MHz	RC	Wien-Bridge	Used in low frequency applications like audio generators.	Not suitable for frequency above 1MHz since the phase shift of lead-lag circuit jointly cause resonance to occur at different frequencies other than resonant frequency.
1 MHz to 500 MHz	LC	Radio frequency oscillators	Used in Laboratory devices and application circuits.	A signal can be feedback with correct amplitude and phase for the sustained oscillations.
Higher frequencies	RC & LC	All oscillators	RF modulation applications	Stray capacitance and lead capacitances determines the frequency of RC and LC oscillators.

Whenever accuracy and stability of oscillation are required, quartz crystal oscillators are preferred. Since the crystal acts as a large inductor in series with a small capacitor, the resonant frequency is not affected by stray capacitances and transistor.

2.16 QUARTZ CRYSTAL OSCILLATOR

To obtain a very high level of oscillator stability a **Quartz Crystal** is generally used as the frequency determining device to produce another types of oscillator circuit known generally as a **Quartz Crystal Oscillator**, (XO).

Piezo-electric Effect

When a voltage source is applied to a small thin piece of quartz crystal, it begins to change shape producing a characteristic known as the **Piezo-electric effect**. This **Piezo-electric Effect** is the property of a crystal.

If electrical charge is applied to quartz crystal, it produces a mechanical force by changing the shape of the crystal. If mechanical force is applied to quartz crystal, it produces a electric charge by changing the shape of the crystal.

Then, piezo-electric devices can be classed as **Transducers** as they convert energy of one kind into energy of another (electrical to mechanical or mechanical to electrical). This piezo-electric effect produces mechanical vibrations or oscillations which are used to replace the LC tank circuit in the previous oscillators. There are many different types of crystal substances which can be used as oscillators with the most important of these for electronic circuits being the quartz minerals because of their greater mechanical strength.

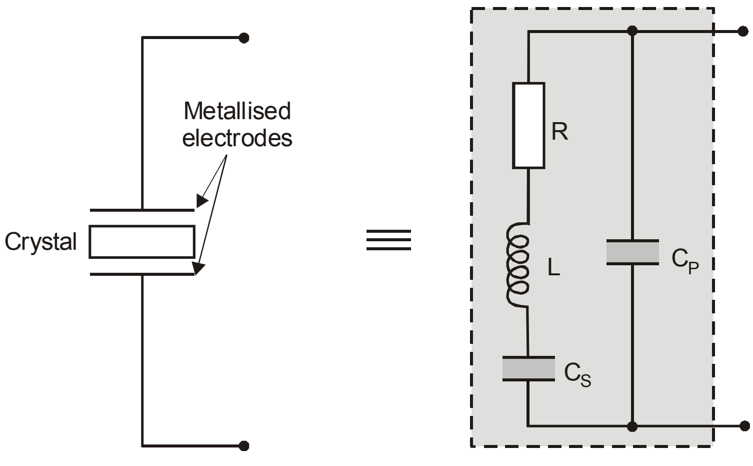
2.16.1 Construction of Quartz Crystal Oscillator

The quartz crystal used in a **Quartz Crystal Oscillator** is a very small, thin piece or wafer of cut quartz with the two parallel surfaces metallised to make the required electrical connections. The physical size and thickness of a piece of quartz crystal is tightly controlled since it affects the final or fundamental frequency of oscillations. The fundamental frequency is called the *crystals "characteristic frequency".*

Then once cut and shaped, the crystal can not be used at any other frequency. In other words, *crystals size and shape determines its fundamental oscillation frequency. The crystals characteristic or resonant frequency is inversely proportional to its physical thickness between the two metallised surfaces.*

2.16.2 Equivalent circuit of Quartz Crystal Oscillator

A mechanically vibrating crystal can be represented by an equivalent electrical circuit.



(a) Quartz Crystal *(b) Equivalent circuit*

Figure 2.38

where

- ***L:*** The inductance arises from the mass of the material. (Large **inductance**).
- ***C_S:*** This capacitance arises from the compliance of the crystal. (small **capacitance**).
- ***R:*** This element arises from the losses in the system. The largest of these arises from the frictional losses of the mechanical vibration of the crystal.(Low **resistance**).
- ***C_P:*** This capacitance in the theoretical quartz crystal equivalent circuit arises from the capacitance between the electrodes of the crystal element. This is often referred to as the **shunt capacitance**.

The equivalent circuit for the quartz crystal shows an RLC series circuit, which represents the mechanical vibrations of the crystal, in parallel with a capacitance, C_p which represents the electrical connections to the crystal.

Resonating frequency is $f_r = \dfrac{1}{2\pi\sqrt{LC}}\sqrt{\dfrac{Q^2}{1+Q^2}}$ Hertz

where Q – Quality factor of crystal.

If the Q factor is less than 10, the resonant frequency is significant reduced.

On the other hand, if the Q factor is greater than 10, the factor $\sqrt{\dfrac{Q^2}{1+Q^2}}$ approximately equal to one, which shall mean it does not affect the resonant frequency of the circuit. The value of L is large in order to reflect the high quality factor.

The quality factor is given by $Q = \dfrac{\omega L}{R} = \dfrac{1}{\omega RC} \approx 50 \times 10^3$

$\sqrt{\dfrac{Q^2}{1+Q^2}}$ approaches to unity, Then the resonating frequency is $f_r = \dfrac{1}{2\pi\sqrt{LC}}$ Hertz.

Crystal resonant frequency is inversely proportional to thickness of the crystal.

$$f \ \alpha \ \frac{1}{t}$$

where t – Thickness

Resonant frequency ranges from 0.5 to 30 MHz.

2.16.3 Crystal parallel and Series resonance

There are two modes in which a crystal oscillator can operate and these can be seen from the equivalent circuit diagram.

- **Series resonance:** This is a standard series resonance condition formed by the series connection of a capacitor and inductor. At the resonant frequency, f_r, the capacitive and inductive reactances cancel and the impedance falls to a minimum equal to the resistance in the circuit, i.e. R.

  Resonating frequency is $f_s = \dfrac{1}{2\pi\sqrt{LC}}$ Hertz

  It is found that in this mode the external circuit has very little effect on the crystal resonance.

- **Parallel resonance:** The parallel resonance for the quartz crystal condition is formed by a capacitor and inductor in parallel. At resonance the impedance of this circuit rises to a maximum. The actual resonant frequency, f_p, derivation for this mode incorporates the inductance along with both capacitors seen in the equivalent circuit.

Resonating frequency is $f_p = \dfrac{1}{2\pi\sqrt{LC_{eq}}}$ Hertz, where $C_{eq} = \dfrac{C_P\, C_S}{C_P + C_S}$

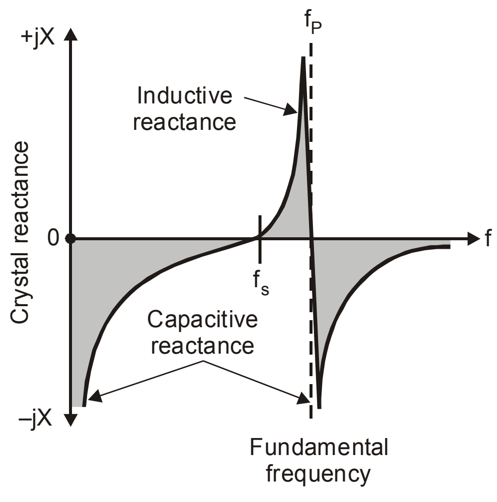


Figure 2.39: Crystal reactance versus Frequency

The slope of the reactance against frequency above, shows that the series reactance at frequency f_S is inversely proportional to C_S.

2.16.4 Reactance function

The reactance functions shown in figure is

$$jx = \frac{1}{j\omega C_P} \cdot \frac{\omega^2 - \omega_S^2}{\omega^2 - \omega_P^2}$$

By neglecting R, then $\omega_S^2 = \frac{1}{LC_S}$ is the series resonant frequency.

$\omega_P^2 = \frac{1}{L\left(\frac{1}{C_S} + \frac{1}{C_P}\right)}$ is the parallel resonant frequency.

Below f_S and above f_P, crystal appears capacitive, i.e. dX/df, where X is the reactance.

Between frequencies f_S and f_P, crystal appears inductive as the two parallel capacitances cancel out.

The point where the reactance values of the capacitances and inductance cancel each other out $X_C = X_L$ is the fundamental frequency of the crystal.

Also, if the crystal is not of a parallel or uniform thickness it have two or more resonant frequencies having both a fundamental frequency and harmonics such as second or third harmonics.

In a **Quartz Crystal Oscillator** circuit the oscillator will oscillate at the crystals fundamental parallel resonant frequency as the crystal always wants to oscillate when a voltage source is applied to it.

2.16.5 Overtone operation

It is also possible to "tune" a crystal oscillator to any even harmonic of the fundamental frequency, (2nd, 4th, 8th etc.) and these are known generally as **Harmonic Oscillators** while **Overtone Oscillators** vibrate at odd multiples of the fundamental frequency, 3rd, 5th, 11th etc). Generally, crystal oscillators that operate at overtone frequencies do so using their series resonant frequency.

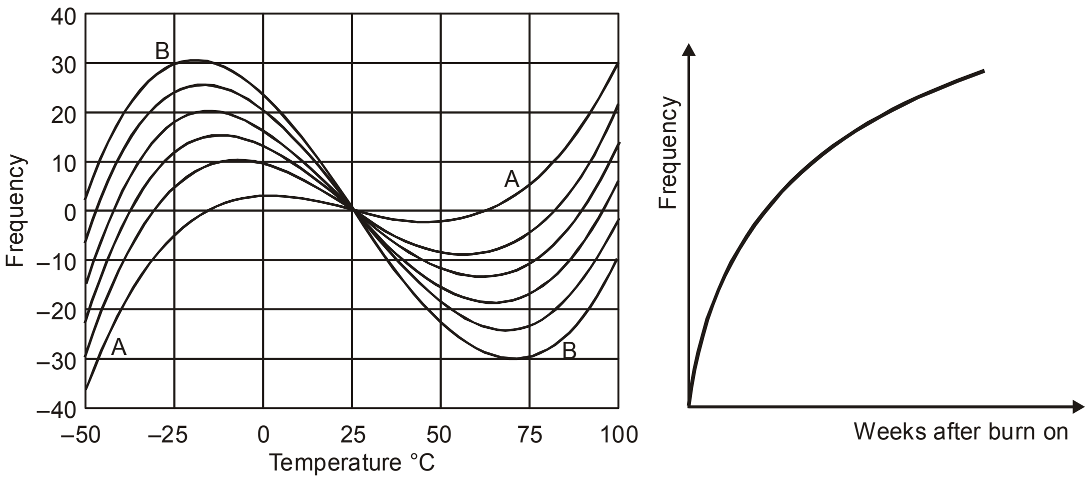
2.16.6 Crystal stability

The most basic element in an oscillator specification is the output frequency. At any given time the oscillator's output frequency will differ from the desired specified frequency resulting in a frequency error.

It comprises of three primary components:

1. **Initial accuracy:** This is generally defined as the difference between the oscillator output frequency and the specified frequency at 25°C at the time of shipment by the oscillator manufacturer.
2. **Aging (Long-term stability):** Aging refers to the continuous change in crystal operating frequency with time, all other parameters (temperature, supply voltage, etc.) held constant. The better the processing of the crystal, the lower the aging rate (that is, the higher the long-term stability).

Figure 2.41 shows a typical aging curve. It illustrates that when a crystal oscillator is initially turned on by the manufacturer, the crystal ages rapidly but its stability improves with time. While the aging rate will typically continue to improve with time, most crystals achieve close to their lowest aging rate within several months after turn-on.



(a) Temperature Stability *(b) Aging of crystal oscillator*

Figure 2.40

3. **Temperature stability:** A temperature stability of for example, ± 10 ppm over 0°C to +50°C means a peak-to-peak frequency change of 20 ppm over the specified temperature range, not referenced to the frequency at any specific temperature.
4. **Short-term frequency stability:** It reveals that it is determined largely in the crystal oscillator by the current noise of the transistor. It is also shown that the change of the oscillation frequency by the change of the DC biasing point of the transistor is due to the change of the load capacitance.

2.17 PIERCE CRYSTAL OSCILLATOR

The design of a **Crystal Oscillator** is very similar to the design of the **Colpitts Oscillator**, except that the LC tank circuit that provides the feedback oscillations has been replaced by a quartz crystal as shown in figure 2.41.

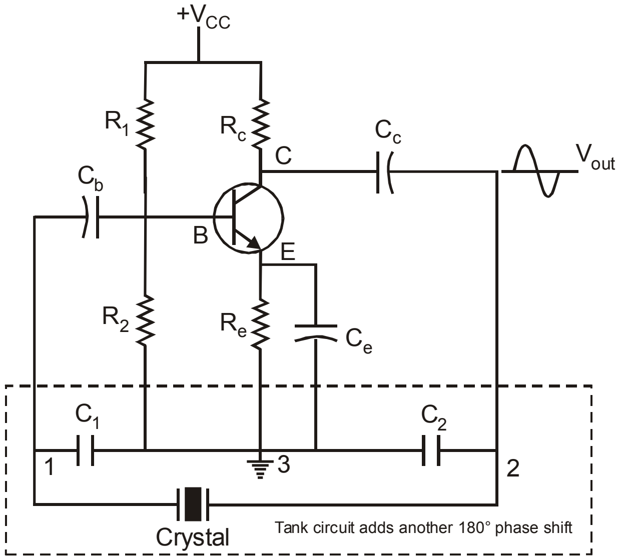


Figure 2.41: A Pierce Crystal Oscillator by Common Emitter mode of Colpitts Oscillator

The input signal to the base of the transistor is inverted at the transistors output. The output signal at the collector is then taken through 180° phase shifting network which includes the crystal operating in a series resonant mode.

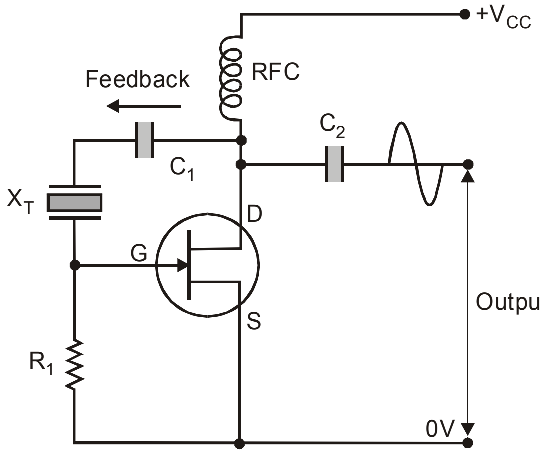


Figure 2.42: Pierce Oscillator using FET

The output is also fed back to the input which is "in-phase" with the input providing the necessary positive feedback.

The resistances R_1, R_2 and R_E provides the necessary DC bias to the transistor. C_E is a bypass capacitor. C_b and C_c are coupling capacitor to provide the stable Q point.

Capacitors, C_1 and C_2 shunt the output of the transistor which reduces the feedback signal. Therefore, the gain of the transistor limits the maximum values of C_1 and C_2. The output amplitude should be kept low in order to avoid excessive power dissipation in the crystal otherwise could destroy itself by excessive vibration.

Advantage of Pierce Crystal Oscillator

1. Main advantage of pierce oscillator is simplicity.

2.18 MILLER OSCILLATOR

In Hartley oscillator circuit, two inductors and one capacitors are used to form tank circuit. If one of the inductor is replaced by crystal when the frequency is greater than series resonant frequency is called **Miller circuit**. In between series-resonant frequency and parallel resonant frequency, the reactance of crystal becomes inductive and hence the crystal is used as Inductor.

The miller oscillator has an average frequency deviation of approximately 1.5 times that of the Pierce circuit.

The crystal behaves as another inductance L_2 between base and ground. The inter-electrode capacitance of transistors acts as a capacitor to generate oscillations in circuit. The crystal decides the operating frequency of oscillator.

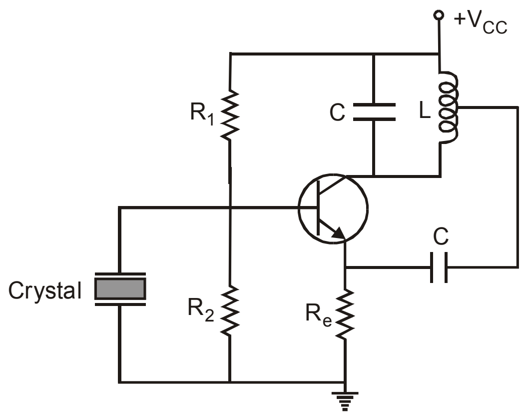


Figure 2.43: Miller Crystal Oscillator

Since the load capacitance is a function of the frequency, a Miller oscillator cannot be operated at more than one frequency and still present the same load capacitance to each crystal unit except by providing for an adjustment of the circuit parameters.

Advantages of Miller crystal oscillator

1. In spite of its greater frequency instability and lack of circuit simplicity as compared with the Pierce circuit, the Miller design is the one most widely used in crystal oscillators.
2. The reason for this popularity is the greater output that can be obtained for the same crystal drive level.

Disadvantage of Miller crystal oscillator

1. Due to low power, Miller oscillator is not used in high frequency applications.

Applications of Miller crystal oscillator

1. Sawtooth generator.
2. Trigger circuits.
3. Timing and phase control circuits.

2.18.1 Comparison between Pierce and Miller circuit

In the pierce circuit, the maximum voltage is thus the maximum permissible across the crystal unit and in the Miller circuit the maximum voltage is (k + 1) times the maximum permissible voltage across the crystal unit, where k is the gain of the stage.

2.19 FREQUENCY STABILITY OF OSCILLATOR

The frequency stability of an oscillator is a measure of its ability to maintain as nearly a fixed frequency as possible over as long a time interval as possible.

These deviations in frequency are caused due to variations in the values of circuit features (circuit components, transistor parameters, supply voltages, stray-capacitances, output load etc.) that determine the oscillator frequency. *The main drawback in transistor oscillators is that the frequency of oscillation is not stable during a long time operation.*

2.19.1 Factors affecting frequency stability

Following factors contribute to the change in frequency.

1. Due to change in temperature, the values of the frequency-determining components, like resistor, inductor and capacitor change which inturn affects the frequency stability.

2. If the operating point of the active device in the circuit is in the non-linear portion of its characteristics, there may be variations in the transistor parameters which, in turn, affects the oscillator frequency stability. So, the operating point, Q is carefully selected to work in the linear portion of the characteristics of the active device.
3. Due to variation in power supply, unstable transistor parameters, change in climatic conditions and aging. Any variation in load coupled to the tank circuit may cause a change in effective resistance of the circuit by transformer action which, in turn, causes the drift in frequency.
4. Changes in load conditions, affect the effective resistance of the tank circuit.
5. The effects of variations in inter-element capacitances affect the frequency of oscillation. It can be neutralized by introducing a swamping capacitor across the offending elements (the introduced capacitor becomes the part of the tank circuit).

The variation of frequency with temperature is given by,

$$S\omega_T = \frac{\Delta\omega/\omega_0}{\Delta T/T_0} \quad \text{(ppmc (Parts per million per °C)}$$

where ω_0 – Desired frequency of oscillation

T_0 – Operating temperature

$\Delta\omega$ – Change in frequency and change in temperature

In absence of automatic temperature control, the effect of temperature on resonant LC circuit can be reduced by selecting an inductance L with positive temperature co-efficient and a capacitance C with negative temperature co-efficient.

The frequency stability is defined as $S\omega = \frac{d\theta}{d\omega}$

where $d\theta$ – Phase shift introduced for a small frequency in nominal frequency.

Circuit giving the larger value of $\frac{d\theta}{d\omega}$ has more stable oscillator frequency.

2.19.2 Improvement of frequency stability

Frequency stability can be improved by,

1. Maintaining the circuit in constant temperature.
2. Maintaining the constant zenar voltage by using zenar diode.
3. Variation in power supply can be overcome by using regulated power supply.

2.20 AMPLITUDE STABILIZATION

If the oscillator output is not stabilized, it can cause distortion in output once it attains the extreme level. So its necessary to reduce the reduce the amplitude inorder to reduce the distortion.

Amplitude of oscillation is determined by the extend to which the loop gain $-\beta A$ is greater than unity. If $-\beta$ is fixed, the amplitude is then determined by A, increasing as A increases until further increase is limited by the amplitude nonlinearity. Amplitude stabilization operates by ensuring that oscillation ceases as the amplifier output approaches a predetermined level. As the output falls to the acceptable level, the circuit continues to oscillator.

2.20.1 Amplitude stabilization in a Phase Shift Oscillator

For phase shift oscillator, the amplifier gain must always exceed 29 to sustain oscillation oscillations.

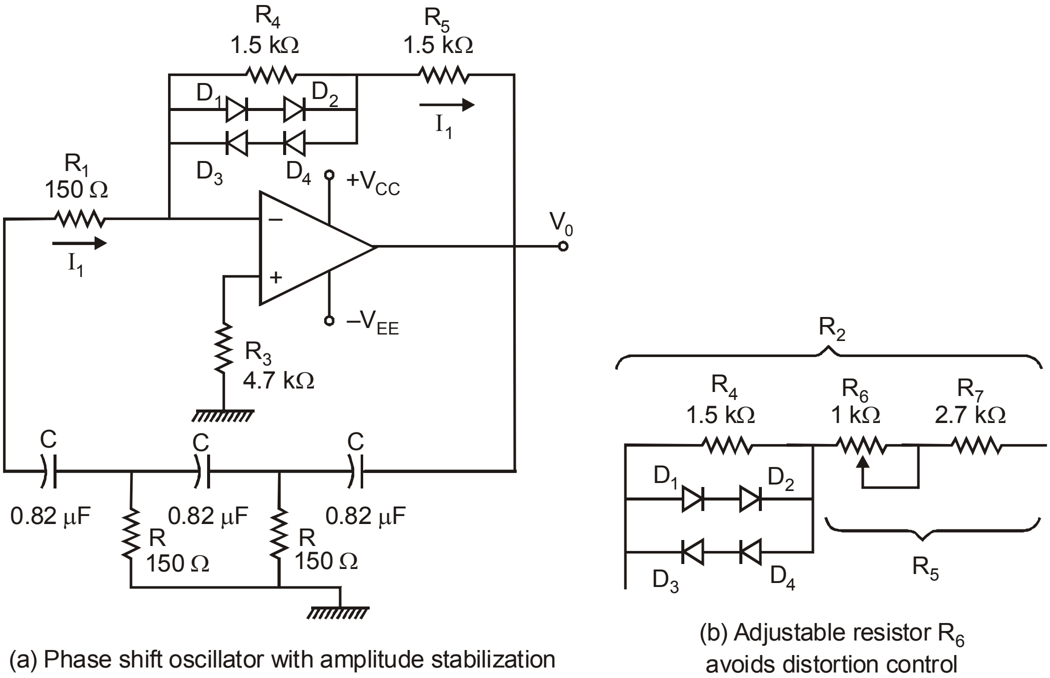


Figure 2.44: Amplitude stabilization in Phase Shift Oscillator

When the output amplitude is low, diode D_1 through D_4 are not forward biased. The diode have no effect on the circuit and the voltage gain is,

$$A_v = \frac{-R_2}{R_1}$$

It is designed to exceed the critical value of 29.

When the output amplitude is large enough to forward biased either D_1 and D_2, or D_3 or D_4 resistor R_4 is short circuited.

The amplifier voltage gain now becomes $A_v = \frac{-R_5}{R_1}$.

This is designed to be too small to sustain oscillations, so the circuit cannot oscillate with high amplitude output. But it can be oscillate with a low amplitude output.

To design the amplitude stabilization circuit, the amplifier is designed in following way.

1. The current I_1 used in calculating the resistors for the feedback network must be large enough for the diodes to be forward biased into the near linear region of their characteristics.
2. Resistor R_1 is then determined from $R_1 = \frac{-V_0/29}{I_1}$.
3. R_2, R_4 and R_5 are calculated as $R_2 = R_1 \times 29$, $R_4 = \frac{2V_f}{I_1}$ and $R_5 = R_2 - R_4$.
4. The result component values should give $\frac{(R_4 + R_5)}{R_1} > 29$ and $\frac{R_5}{R_1} < 29$.
5. Some distortion can still occur in the output waveform if $\frac{(R_4 + R_5)}{R_1} > 29$.
6. Attempt to make $\frac{(R_4 + R_5)}{R_1} = 29$ may result in the circuit not oscillating.

This is solved by making a portion of R_5 adjustable.

2.20.2 Amplitude stabilization in Wien bridge oscillator

The circuit in figure 2.45 operates exactly the same way as we discussed in phase shift oscillator.

Amplitude stabilization by Diode:

Resistor R_5 becoming shorted out by the diodes when the output amplitude exceeds the desired level. With R_5 shorted, so $R_5 = R_6$ the amplifier gain $A_v = 1 + \frac{R_3}{R_4}$ is not large enough to sustain oscillations.

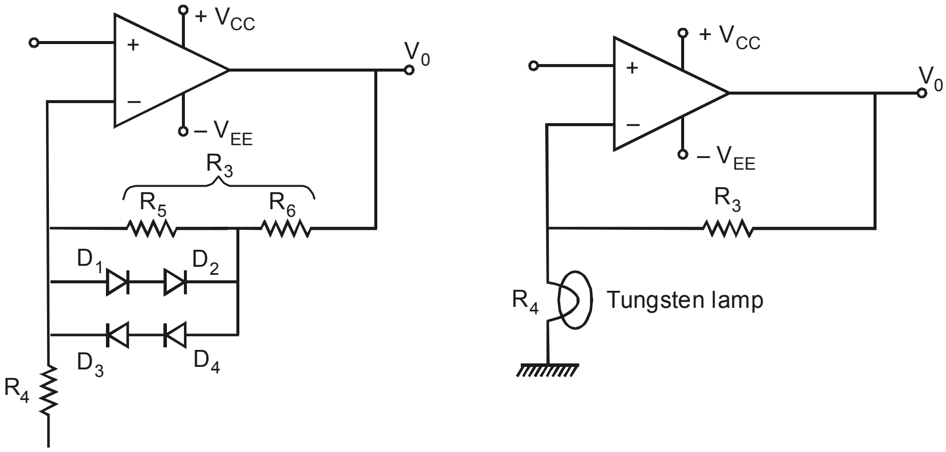


Figure 2.45: Amplitude stabilization

Amplitude stabilization by Tungston:

Tungston filament lamp is used instead R_4 and it has effect of reducing the amplifier voltage gain when the output amplitude is larger than desired.

As output grows large, the current through lamp filament increases. The resultant increased heat of filament increases its resistance.

As the amplifier gain $A_v = \frac{R_3 + R_4}{R_4}$, any increases in R_4 reduces A_v.

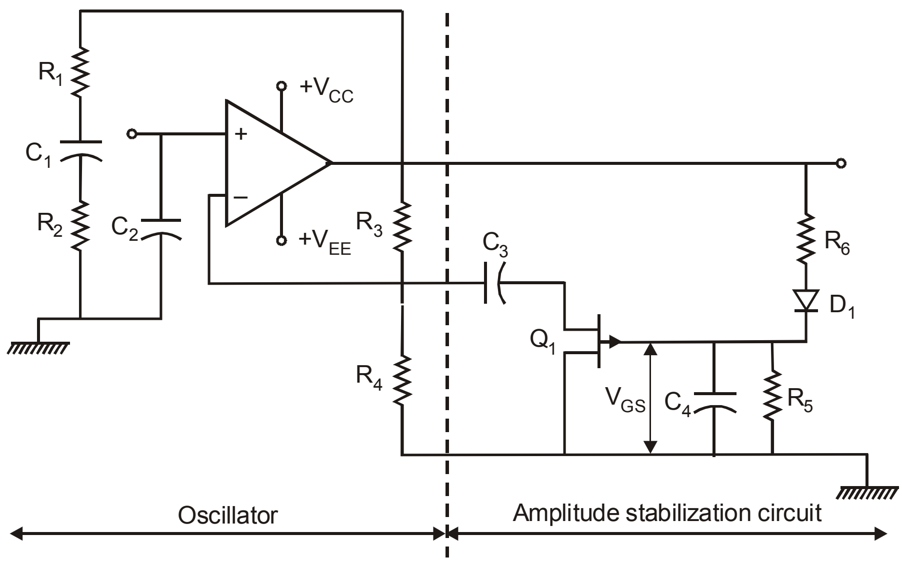


Figure 2.46: Amplitude stabilization in Wien Bridge Oscillator

Amplitude stabilization by FET

It stabilizes the output voltage by reducing the amplifier gain when the output amplitude is greater than the desired level. The channel resistance of (p-channel) FET Q_1 is in parallel with R_4. Capacitor C_3 ensures that Q_1 has no effect on the DC bias conditions of the circuit.

The bias voltage of the FET gate is derived from the amplifier output, which is rectified by diode D_1 and potentially divided across resistor R_6 and R_7. As the amplitude increases, the bias voltage of p-channel FET increases the resistance of the FET which is across R_4. Thus effective R_4 value increase which reduces the gain and stabilizes the output amplitude.

2.21 COMPARISON OF VARIOUS OSCILLATOR

2.21.1 Comparison of RC and LC circuit

S.No.	*LC*	*RC*
1.	The circuit consists of an inductive coil L and a capacitor, C to produce the oscillations are called LC produce oscillators.	The circuit consists of resistors and capacitors arranged in ladder manner tothe oscillations are called RC oscillators.
2.	There is a 180° phase shift in amplifier along with the original 180° the phase shift in the feedback loop provides total phase shift of 360°.	Here, the input is shifted 180° through amplifier stage and 180° again through a second inverting stage giving "180°+180° = 360°"of phase shift.
3.	The frequency of oscillation is $f_r = \frac{1}{2\pi\sqrt{LC}}$ Hertz	The frequency of oscillation is $f_r = \frac{1}{2\pi RC\sqrt{6+4K}}$ Hertz; Where $K < 2.7$
4.	Fine performer at high frequency.	Good frequency stability.
5.	Used in radio receivers and transmitters.	Used in musical instruments, oscillators, voice synthesis, and GPS units.

2.21.2 Comparison of RC and Wien bridge

S.No.	*RC*	*Wien bridge*
1.	Feedback network has 3 sections of RC network.	Feedback network consists of Lead-lagnetwork.
2.	Feedback network introduces 180° phase shift.	Feedback network does not introduces 180° phase shift.
3.	The frequency of oscillation is $f_r = \frac{1}{2\pi RC\sqrt{6}}$ Hertz	The frequency of oscillation is $f_r = \frac{1}{2\pi RC}$ Hertz
4.	OPAMP is used in inverting mode.	OPAMP is used in Non-inverting mode.
5.	OPAMP circuit introduces 180° phase shift.	OPAMP circuit does not introduces 180° phase shift.
6.	Amplifier gain is $\lvert A \rvert \geq 29$.	Amplifier gain is $\lvert A \rvert \geq 3$.
7.	Used at high frequency of oscillation.	Not used at high frequency of oscillation.
8.	Frequency variation is difficult.	It needs two transistors and a large number of other components for frequency variation.
9.	Used in musical instruments, oscillators voice synthesis, and GPS units.	Used for measurement of audio frequency.

SOLVED PROBLEMS

Based on Hartley Oscillator

EXAMPLE 1

In transistorized Hartley oscillator, two inductances are 2 mH and 20 μH while the frequency changes from 950 KHz to 2050 KHz. Calculate the range over which capacitor is to be varied.

Solution:

Given, for a Hartley oscillator

L_1 = 2 mH

L_2 = 20 μH

f_1 = 950 KHz

f_2 = 2050 KHz

To find the range over which capacitance is to be varied

Frequency of oscillation of Hartley oscillator is

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

Therefore,

$$C = \frac{1}{4\pi^2 (L_1 + L_2) f_o^2}$$

When f_o = 950 KHz;

$$C = \frac{1}{4\pi^2\left[\left(2\times 10^{-3} + 20\times 10^{-6}\right)\left(950\times 10^3\right)^2\right]}$$

$$= 13.89 \text{ pF}$$

When f_o = 2050 KHz;

$$C = \frac{1}{4\pi^2\left[\left(2\times 10^{-3} + 20\times 10^{-6}\right)\left(2050\times 10^3\right)^2\right]}$$

$$= 2.98 \text{ pF}$$

Hence, the range of capacitance is from 2.98 pF to 13.89 pF.

EXAMPLE 2

In the Hartley oscillator, L_2 = 0.4 mH and C = 0.004 μF. If the frequency of the oscillator is 120 KHz, find the value of L_1. Neglect the mutual inductance.

Solution:

The frequency of Hartley oscillator is given by,

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

Therefore,
$$L_1 = \frac{1}{4\pi^2 f_o^2 C} - L_2$$

$$= \frac{1}{4\pi^2 \left(120 \times 10^3\right)^2 \times 0.004 \times 10^{-6}} - 0.4 \times 10^{-3}$$

$$= 0.44 \times 10^{-3} - 0.4 \times 10^{-3}$$

$$= 0.04 \text{ mH}$$

EXAMPLE 3

In a Hartley oscillator, the value of the capacitor in the tuned circuit is 500 pF and the two sections of coil have inductances 38 μH and 12 μH. Find the frequency of oscillations and the feedback factor β.

Solution:

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

Where $L = L_1 + L_2 = 38 \times 10^{-6} + 12 \times 10^{-6} = 50 \times 10^{-6}$ and C = 500 pF

Therefore,
$$f_o = \frac{1}{2\pi\sqrt{50 \times 10^{-6} \times 500 \times 10^{-12}}} = 1 \text{ MHz}$$

Feedback factor,
$$\beta = \frac{L_1}{L_2} = \frac{38 \times 10^{-6}}{12 \times 10^{-6}} = 3.166$$

EXAMPLE 4

If L_1 = 1 mH and L_2 = 2 mH and C = 0.1 μF. What is the frequency of oscillation of Hartley oscillator? (NOV/DEC - 2007)

Solution:

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

$$= \frac{1}{2\pi\sqrt{0.1\times10^{-9}\left(1\times10^{-3} + 2\times10^{-3}\right)}}$$

$$= 290.6 \text{ KHz}$$

EXAMPLE 5

If L_1 = 0.2 mH and L_2 = 0.3 mH and C = 0.003 μF. Calculate the frequency of oscillations of Hartley oscillator? (MAY / DEC - 2012)

Solution:

$$f = \frac{1}{2\pi\sqrt{CL_{eq}}} \qquad \text{where } L_{eq} = L_1 + L_2$$

$$= 0.2 + 0.3 = 0.5 \text{ mH}$$

$$f = \frac{1}{2\pi\sqrt{0.003\times10^{-6}\times0.5\times10^{-3}}}$$

$$= 129.95 \text{ KHz}$$

Based on Colpitts Oscillator

EXAMPLE 6

In the Colpitts oscillator, C_1 = 200 pF and C_2 = 50 pF. If frequency of the oscillator is 1 MHz, find the value of the inductor. Also find the required gain for oscillation. (NOV / DEC - 2007)

Solution:

The frequency of the Colpitts oscillator is given by,

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

Therefore,
$$L = \frac{C_1 + C_2}{4\pi^2 f_o^2 C_1 C_2}$$

$$= \frac{200 \times 10^{-12} + 50 \times 10^{-12}}{4\pi^2 \left(1 \times 10^6\right)^2 \times 200 \times 10^{-12} \times 50 \times 10^{-12}}$$

$$= 0.633 \text{ mH}$$

The voltage gain required to produce oscillation is,

$$A_V > \frac{C_1}{C_2} = \frac{200 \times 10^{-12}}{50 \times 10^{-12}} = 14$$

EXAMPLE 7

In a Colpitts oscillator, the values of the inductors and capacitors in the tank circuit are L = 40 mH, C_1 = 100 pF and C_2 = 500 pF.

i) Find the frequency of oscillation.

ii) If the output voltage is 10 V, find the feedback voltage.

iii)Find the minimum gains if the frequency is changed by changing L alone.

iv)Find the value of C_1 for a gain of 10.

v) Also, find the new frequency.

(MAY - 2007, 11 / DEC - 12)

Solution:

i) In a Colpitt's oscillator, a series combination of C_1 and C_2 which is in parallel with inductance L and frequency of oscillation is,

$$f = \frac{1}{2\pi\sqrt{LC_{eq}}} = \frac{1}{2\pi\sqrt{\frac{LC_1 C_2}{(C_1 + C_2)}}}$$

Substituting the values, we get,

$$f_o = \frac{1}{2\pi\sqrt{\frac{40 \times 10^3 \times 100 \times 10^{-12} \times 500 \times 10^{-12}}{100 \times 10^{-12} + 500 \times 10^{-12}}}}$$

$$= 87.2 \text{ KHz}$$

ii) The output potential is across C_1 and is proportional to X_{C_1}, and the feedback voltage is across C_2 and proportional to X_{C_2}. Therefore,

$$\frac{V_o}{V_f} = \frac{X_{C_1}}{X_{C_2}} = \frac{\left(\frac{1}{\omega C_1}\right)}{\left(\frac{1}{\omega C_2}\right)} = \frac{C_2}{C_1}$$

Hence, $$V_f = \frac{V_o C_1}{C_2} = \frac{10 \times 100 \times 10^{-12}}{500 \times 10^{-12}} = 2 \text{ V}$$

iii) Since the gain depends upon C_1 and C_2 only and is independent of L,

$$\text{Gain} = \frac{500 \times 10^{-12}}{100 \times 10^{-12}} = 5$$

iv) When the gain is equal to 10, $\frac{C_2}{C_1} = 10$

Therefore, $$C_1 = \frac{C_2}{C_1} = \frac{500 \times 10^{-12}}{10} = 50 \text{ pF}$$

v) The frequency of oscillation is,

$$f_o = \frac{1}{2\pi\sqrt{\frac{40 \times 10^{-3} \times 50 \times 10^{-12} \times 500 \times 10^{-12}}{50 \times 10^{-12} + 500 \times 10^{-12}}}}$$

$$= 118.1 \text{ KHz}$$

EXAMPLE 8

A Colpitts oscillator is designed with C_1 = 100 pF and C_2 = 7500 pF. Inductance is variable. Determine the range of inductance values if frequency of oscillation vary between 950 KHz and 2050 KHz. (APR / MAY - 2010)

Solution:

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

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{100 \times 10^{-12} \times 7500 \times 10^{-12}}{100 \times 10^{-12} + 7500 \times 10^{-12}} = 98.6 \text{ pF}$$

$$950 \times 10^3 = \frac{1}{2\pi\sqrt{L_1 \times 98.6 \times 10^{-12}}}$$

$$2050 \times 10^3 = \frac{1}{2\pi\sqrt{L_2 \times 98.6 \times 10^{-12}}}$$

Range of Inductance $L_1 = 284.41$ µH and $L_2 = 61.07$ µH

EXAMPLE 9

Draw the feedback circuit of Colpitts oscillator. Obtain the value of equivalent series capacitance required if it uses a L of 100 mH and is to oscillate at 40 KHz. (MAY - 2013)

Solution:

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

$$40 \times 10^3 = \frac{1}{2\pi\sqrt{100 \times 10^3 \times L_{eq}}}$$

$$\boxed{C_{eq} = 158.31 \text{ pF}}$$

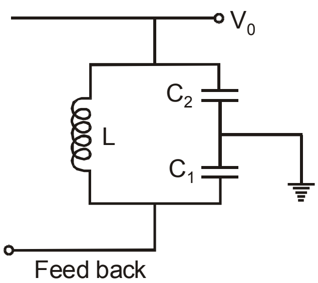


Figure Feedback Circuit

EXAMPLE 10

In Colpitts oscillator, C_1 = 0.0001 µf, C_2 = 0.1 µF and L = 10 µH. Find the frequency of oscillator, feedback factor and voltage gain. (DEC - 2004)

Solution:

Frequency of oscillator $f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}$

where $C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{0.001 \times 10^{-6} \times 0.01 \times 10^{-6}}{0.001 \times 10^{-6} + 0.01 \times 10^{-6}} = 9.09 \times 10^{-10}$

$$\therefore \quad f = \frac{1}{2\pi\sqrt{LC_{eq}}} = \frac{1}{2\pi\sqrt{10 \times 10^{-6} \times 9.09 \times 10^{-10}}}$$

$$= 1.6692 \text{ MHz}$$

$$\text{Voltage gain } (A_V) = \frac{C_2}{C_1} = \frac{0.01 \times 10^{-6}}{0.001 \times 10^{-6}} = 10$$

For oscillators, $A_V B = 1$ B - Feeback factor

$$B = \frac{1}{A_v} = \frac{1}{10} = 0.1$$

$$\text{Voltage gain } (A_V) = \frac{1}{A_v} = \frac{1}{10}$$

Based on Clapp Oscillator

EXAMPLE 11

Calculate the frequency of oscillation for the Clapp oscillator with C_1 = 0.1 μF. C_2 = 1 μF, C_3 = 100 pF and L = 470 μH. (MAY / JUNE - 2007)

Solution:

C_1 = 0.1 μF, C_2 = 1 μF, C_3 = 100 pF, L = 470 μH

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

$$= \frac{1}{0.1 \times 10^{-6}} + \frac{1}{1 \times 10^{-6}} + \frac{1}{100 \times 10^{-12}}$$

$$\therefore \quad C_{eq} = 99.89 \text{ pF}$$

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

$$= \frac{1}{2\pi\sqrt{470 \times 10^{-6} \times 99.89 \times 10^{-12}}}$$

$$= \mathbf{734.53 \text{ KHz}}$$

EXAMPLE 12

Calculate the inductance value to produce 734.5 KHz frequency of oscillation in Clapp oscillator having C_1 = 0.1 μF, C_2 = 1 μF, C_3 = 100 μF.

(MAY / JUNE - 2008)

Solution:

f = 734.5 KHz, C_1 = 0.1 μF, C_2 = 1 μF, C_3 = 100 μF

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{0.1 \times 10^{-6}} + \frac{1}{1 \times 10^{-6}} + \frac{1}{100 \times 10^{-6}}$$

$$\therefore \quad C_{eq} = 9.0826 \times 10^{-8} \text{ F}$$

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

$$\text{i.e.} \quad 734.5 \times 10^3 = \frac{1}{2\pi\sqrt{L \times 9.0826 \times 10^{-8}}}$$

$$L = \mathbf{0.5169\ \mu H}$$

Based on Tuned Collector Oscillator

EXAMPLE 13

A tuned collector oscillator in a radio receiver has a fixed inductance of 60 μH and has to be tunable over the frequency band of 400 to 120 KHz. Find the range of variable capacitor to be used. (MAY / DEC - 2011)

Solution:

The resonant frequency is given by,

$$f_o = \frac{1}{2\pi\sqrt{L_P C}}$$

Therefore,

$$C = \frac{1}{4\pi^2 f_o^2 L_P}$$

When, f_o = 400 KHz,

$$C = \frac{1}{4\pi^2\left(400 \times 10^3\right)^2 \times 60 \times 10^{-6}} = 2641 \text{ pF}$$

When, f_o = 1200 KHz, $C = \dfrac{1}{4\pi^2\left(1200\times10^3\right)^2\times60\times10^{-6}}$ = 293 pF

Hence, the capacitor range required is 293 - 2641 pF.

EXAMPLE 14

A tank circuit contains an inductance of 1 mH. Find out the range of tuning capacitor value if the resonant frequency ranges from 540-1650 KHz.

Solution:

Given L = 1 mH

f_o ranges from 540-1650 KHz

We know that, $f_o = \dfrac{1}{2\pi\sqrt{LC}}$

Therefore, $C = \dfrac{1}{4\pi^2 f_o^2 L}$

Here, $C_{max} = \dfrac{1}{4\pi^2\left(540\times10^3\right)^2\times10^{-3}}$ = 86.86 pF

$C_{min} = \dfrac{1}{4\pi^2\left(1650\times10^3\right)^2\times10^{-3}}$ = 9.3 pF

Hence, the value of capacitance ranges from 9.3-86.86 pF.

Based on RC Phase Shift Oscillator

EXAMPLE 15

In an RC phase shift oscillator, if $R_1=R_2=R_3=200$ kΩ and $C_1=C_2=C_3=100$ pF, find the frequency of oscillations. (APR / MAY - 2011)

Solution:

The frequency of an RC phase shift oscillator is given by, $f_o = \dfrac{1}{2\pi RC\sqrt{6}}$

$$= \frac{1}{2\pi\times200\times10^3\times100\times10^{-12}\sqrt{6}}$$

$$= 3.248 \text{ KHz}$$

EXAMPLE 16

In an RC phase shift oscillator, if frequency of oscillator is 955 Hz and $R_1 = R_2 = R_3 = 680\ k\Omega$. Find the value of capacitor. (DEC - 2010)

Solution:

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

$$C = \frac{1}{2\pi \times 680 \times 10^3 \times 955}$$

$$\boxed{C = 0.245\ nF}$$

EXAMPLE 17

Find the capacitor C and h_{fe} for the transistor to provide a resonating frequency of 10 KHz of a transistorized phase shift oscillator. Assume $R_1 = 25\ k\Omega$, $R_2 = 60\ k\Omega$, R_C 40 $k\Omega$, $R = 7.1\ k\Omega$ and $h_{ie} = 1.8\ k\Omega$.

Solution:

For a phase shift oscillator,

$f_o = 10$ KHz, $R_1 = 25\ k\Omega$, $R_2 = 60\ k\Omega$, $R_C = 40\ k\Omega$, $R = 7.1\ k\Omega$, $h_{ie} = 1.8\ k\Omega$

i) To find capacitance, C:

Frequency of oscillation is,

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

$$C = \frac{1}{2\pi f_o R\sqrt{6 + \frac{4R_C}{R}}}$$

$$= \frac{1}{2\pi \times 10 \times 10^3 \times 7.1 \times 10^3 \sqrt{6 + \frac{4 \times 40 \times 10^3}{7.1 \times 10^3}}}$$

$$= 0.41\ nF$$

ii) To find h_{fe}:

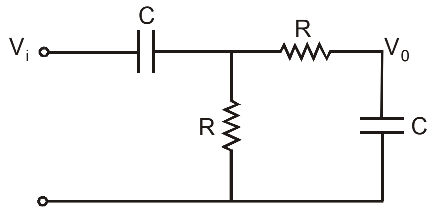
We know that $$h_{fe} \geq 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R}$$

$$\geq 23 + 29\frac{7.1\times10^3}{40\times10^3} + 4\times\frac{40\times10^3}{7.1\times10^3}$$

$$\boxed{h_{fe} \geq 50.67}$$

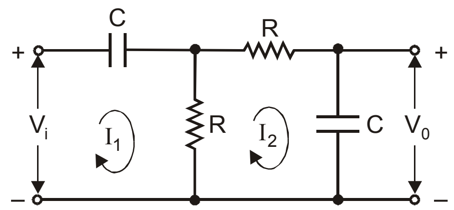
EXAMPLE 18

Design an oscillator with network shown in the feedback path of the amplifier to generate a sine wave of 2 KHz. (MAY - 2006)



Solution:

Consider the feedback network as shown in the figure.



Given feedback network

Applying KVL to the two loops,

$$V_i = I_1\frac{1}{j\omega C} + R(I_1 + I_2) \quad ...(1)$$

$$0 = (I_2 + I_1)R + I_2 R + I_2\frac{1}{j\omega C} \quad ...(2)$$

$$\therefore \quad I_1\left[R - \frac{j}{\omega C}\right] - I_2 R = V_i \quad ...(1a)$$

$$-I_1 R + I_2\left[2R - \frac{j}{\omega C}\right] = 0 \qquad \text{...(2a)}$$

$$\therefore \qquad \Delta = \begin{vmatrix} R - \dfrac{j}{\omega C} & -R \\ -R & 2R - \dfrac{j}{\omega C} \end{vmatrix} = R^2 - \frac{1}{\omega^2 C^2} - j\frac{3R}{\omega C}$$

$$\Delta_2 = \begin{vmatrix} R - \dfrac{j}{\omega C} & V_i \\ -R & 0 \end{vmatrix} = V_i\, R$$

But $\qquad V_o = I_2 \dfrac{1}{j\omega C} = -I_2 \dfrac{1}{\omega C} \quad$ where $I_2 = \dfrac{\Delta_2}{\Delta}$

$$\therefore \qquad V_o = \frac{-j}{\omega C} \times \frac{V_i R}{R^2 - \dfrac{1}{\omega^2 C^2} - j\dfrac{3R}{\omega C}}$$

$$\therefore \qquad \beta = \frac{V_o}{V_i} = \frac{-j\dfrac{R}{\omega C}}{R^2 - \dfrac{1}{\omega^2 C^2} - j\dfrac{3R}{\omega C}}$$

Rationalise the expression for β,

$$\therefore \beta = \frac{-j\dfrac{R}{\omega C}\left[\left(R^2 - \dfrac{1}{\omega^2 C^2}\right) + j\dfrac{3R}{\omega C}\right]}{\left[\left(R^2 - \dfrac{1}{\omega^2 C^2}\right) - j\dfrac{3R}{\omega C}\right]\left[\left(R^2 - \dfrac{1}{\omega^2 C^2}\right) + j\dfrac{3R}{\omega C}\right]}$$

$$= \frac{+\dfrac{3R^2}{\omega^2 C^2} - \dfrac{jR}{\omega C}\left(R^2 - \dfrac{1}{\omega^2 C^2}\right)}{\left[\left(R^2 - \dfrac{1}{\omega^2 C^2}\right)^2 + \dfrac{9R^2}{\omega^2 C^2}\right]}$$

According to Barkhausen criteria, phase shift of β must be 0°. So usuage of 2 stage amplifier gives 360° phase shift.

Thus the imaginary part of β must be zero.

$$R^2 - \frac{1}{\omega^2 C^2} = 0 \Rightarrow \therefore \quad \omega^2 = \frac{1}{R^2 C^2} \text{ i.e. } \omega = \frac{1}{RC}$$

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

At this frequency, the magnitude of β is,

$$|\beta| = \left| \frac{\dfrac{+3R^2}{\left(\dfrac{1}{R^2C^2} \times C^2\right)}}{R^2 - \dfrac{1}{\dfrac{1}{R^2C^2} \times C^2} + \dfrac{9R^2}{\dfrac{1}{R^2C^2} \times C^2}} \right| = \left| \frac{+3R^4}{9R^4} \right| = \frac{1}{3}$$

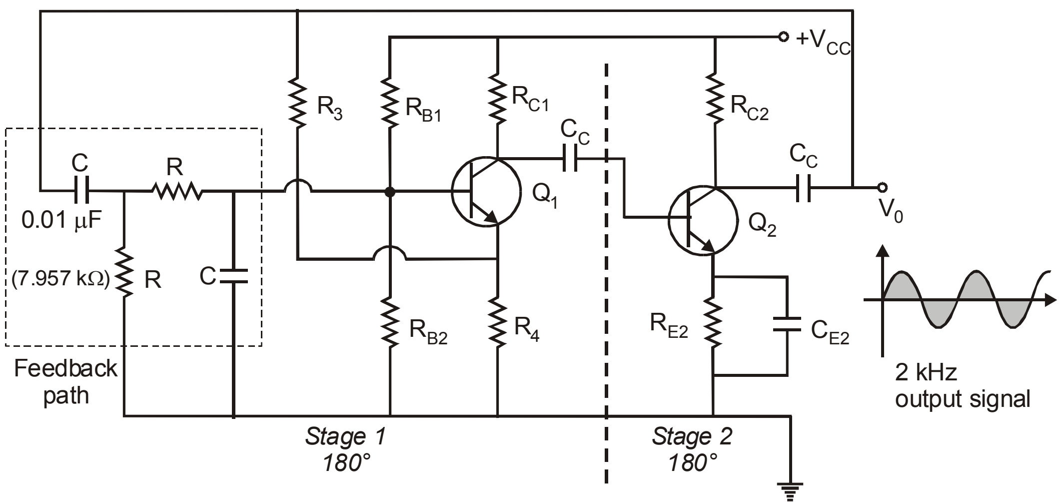
Let A be the effective gain of the amplifier stage then, $|A\beta| \geq 1$

$$\therefore \qquad \boxed{|A| \geq \frac{1}{|\beta|} \geq 3}$$

Given, $\qquad f = 2 \text{ KHz} = \dfrac{1}{2\pi RC}$

Choose $\qquad C = \mathbf{0.01\ \mu F}$ i.e $R = \dfrac{1}{2\pi fC} = \mathbf{7.957\ k\Omega}$

The transistorised oscillator with two stage amplifier is shown in the Figure.



Using resistance R_4, the output amplitude can be controlled and stablised. The gain of two stage amplifier must be greater than 3 to start the oscillations.

EXAMPLE 19

Design a RC phase shift oscillator to generate 5 KHz sine wave with 20 V peak to peak amplitude. Draw the designed circuit. Assume h_{fe} = 150. (MAY - 2006)

Solution:

Given $h_{fe} = 150$, $f = 5$ KHz

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

$$\therefore \quad 150 = 4k + 23 + \frac{29}{k}$$

$$\therefore \quad 4k^2 - 127k + 29 = 0$$

$$k = 31.52,\ 0.23$$

Prefer lower value of k = 0.23.

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

Prefer $\quad C = 1000$ pF

$$\therefore \quad 5 \times 10^3 = \frac{1}{2\pi R \times 1000 \times 10^{-12} \times \sqrt{6 + 4 \times 0.23}}$$

$$\therefore \quad R = 12.1\ \text{k}\Omega = \mathbf{12\ k\Omega}$$

$$k = \frac{R_C}{R} \quad \text{i.e } R_C = KR = \mathbf{2.7\ k\Omega}$$

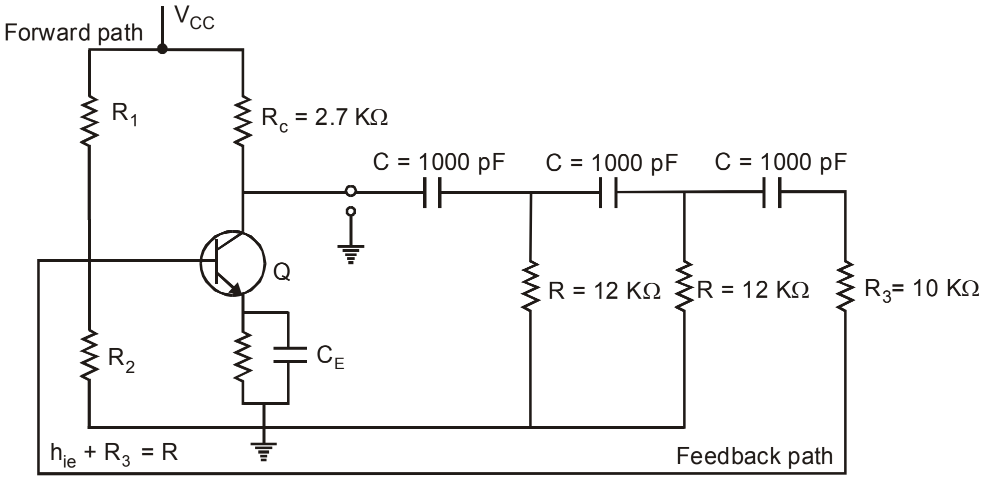
Assuming biasing resistances is large, so it is neglected and selecting transistor with $h_{ie} = 2$ kΩ,

$$R_i^{'} = h_{ie} = 2\ \text{k}\Omega$$

∴ Last resistance in phase shift network,

$$R_3 = R - R_i^{'} = 12 - 2 = \mathbf{10\ k\Omega}$$

Using the **back to back** connected zener diodes of 9.3 V (V_Z) each at the output of emitter follower and using this at the output of the oscillator, the output amplitude can be controlled to 10 V i.e. 20 V peak to peak. The zener diode 9.3 V and forward biased diode of 0.7 V gives total 10 V.



Based on Wien bridge oscillator

EXAMPLE 20

In a Wien-bridge oscillator, R = 100 kΩ and frequency of oscillation is 100 KHz. Find C. (NOV / DEC - 2008)

Solution:

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

$$C = \frac{1}{2\pi f_o} = \frac{1}{2\pi \times 100 \times 10^3 \times 10 \times 10^3} = \mathbf{159\ pF}$$

EXAMPLE 21

A Wien-bridge oscillator is used for operations at 9 KHz. If the value of R is 100 Ω, what is the value of C required? (APR / MAY - 2011)

Solution:

$$f = \frac{1}{2\pi RC} \Rightarrow 9 \times 10^3 = \frac{1}{2\pi \times 100 \times 10^3 \times C}$$

$$\boxed{C = 0.1768 \text{ nF}}$$

Based on Crystal Oscillator

EXAMPLE 22

A crystal has L = 0.33 H, C = 0.065 pF and C_M = 1 pF with r = 5.5 kΩ. Find,

i) Series resonant frequency.

ii) Parallel resonant frequency.

iii) By what percent does the parallel resonant frequency exceed the series resonant frequency?

iv) Find the Q factor of the crystal.

(NOV / DEC - 2008, DEC 11)

Solution:

a) Repeat the same for L = 0.7 H, C = 0.1 pF, R = 100 o and C_m = 2 pF.

i) $$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.33 \times 0.065 \times 10^{-12}}} = \mathbf{1.087 \ MHz}$$

ii) $$C_{eq} = \frac{C C_M}{C + C_M} = \frac{0.065 \times 1}{0.065 + 1} = \mathbf{0.061 \ pF}$$

$$\therefore \quad f_p = \frac{1}{2\pi\sqrt{LC_{eq}}} = \frac{1}{2\pi\sqrt{0.33 \times 0.061 \times 10^{-12}}} = \mathbf{1.121 \ MHz}$$

iii) $$\% \text{ increase} = \frac{1.121 - 1.087}{1.087} \times 100 = \mathbf{3.127\%}$$

iv) $$Q = \frac{\omega_s L}{R} = \frac{2\pi f_s L}{R} = \frac{2\pi \times 1.087 \times 10^6 \times 0.33}{55 \times 10^3} = \mathbf{409.789}$$

b) Solution like (a) we get

f_s = 1.902 MHz, f_p 1907 MHz and **Q = 8365.4**

EXAMPLE 23

A crystal has following parameters L = 0.5 H, C = 0.05 pF and monitoring capacitance C_M = 2 pF. Calculate its series and parallel resonating frequencies.

(NOV / DEC - 2010)

Solution:

Given L = 0.5 H, C = 0.05 pH and C_M = 2 pF

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

$$= \frac{1}{2\pi\sqrt{0.5 \times 0.05 \times 10^{-12}}} = \mathbf{1.006\ MHz}$$

$$C_{eq} = \frac{C\,C_M}{C + C_M} = \frac{0.05 \times 10^{-12} \times 2 \times 10^{-12}}{0.05 \times 10^{12} + 2 \times 10^{-12}} = 0.049\ \text{pF}$$

Parallel resonating frequency,

$$R_p = \frac{1}{2\pi\sqrt{L_{eq}}} = \frac{1}{2\pi\sqrt{0.5 \times 0.049 \times 10^{-12}}} = \mathbf{1.019\ MHz}$$

EXAMPLE 24

A parallel resonant circuit has inductance of 150 MHz and capacitance of 100 pF. Find the resonant frequency. **(DEC - 2011)**

Solution:

For parallel resonance $$f_p = \frac{1}{2\pi\sqrt{L_{eq}}}$$

$$f_p = \frac{1}{2\pi\sqrt{150 \times 10^{-6} \times 100 \times 10^{-12}}} = \mathbf{1.3\ MHz}$$

TWO MARKS QUESTIONS AND ANSWERS

1. What is an oscillator?

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

2. List out the classification of oscillator? (Nov/Dec 2005)

Refer figure 2.2.

3. What is the difference between open loop and closed loop gain of the circuit?

S.No.	*Open loop gain*	*Closed loop gain*
1.	The gain of the amplifier is ratio of output to input when no feedback is used is called open loop gain.	The ratio of the output to input, considering the overall effect of the feedback is called closed loop gain.

4. State the Barkhausen criterion for an oscillator.

(May 2003, 2004, 2012, 2013, 2014, Dec 2011)

a) The total phase shift around a loop, as the signal proceeds from input through amplifier, feedback network back to input again, completing a loop, is precisely 00 or 3600.

b) The magnitude of the product of the open loop gain of the amplifier (A) and the feedback factor β is unity. i.e., $|A\ \beta| = 1$.

5. Define LC circuit.

The circuit consists of an inductive coil, L and a capacitor, C to produce the oscillations are called LC oscillators. L and C forms LC tank circuit. This circuit is also called as resonating circuit or tuned circuit.

6. Give the expression for the frequency of oscillation of Hartley and Colpitt oscillator. (May 2003)

The frequency of oscillation are obtained as follows,

For Hartley oscillator,

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

For Colpitts oscillator,

$$f_r = \frac{1}{2\pi\sqrt{LC\,eq}} \text{Hertz} \quad \text{Where } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

7. Write the advantages of Hartley oscillator.

a) Radio frequency choke(RFC) which connects the dc supply to the circuit but isolate the dc supply from the high frequency oscillations generated in the feedback circuit

b) More stable than Armstrong oscillators.

c) Automatic base bias is possible.

8. Define Colpitt oscillator.

If the LC oscillator uses two capacitive reactances and one Inductive reactance in its feedback network, it is called as Colpitts oscillator.

9. State the advantages of Clapps oscillator. (Nov/Dec 2004)

1. Stability is stable and accurate
2. Good frequency stability

10. List out the types of Franklin Oscillator.

1. Parallel Resonating Franklin Oscillator
2. Series Resonating Franklin Oscillator

11. Draw the circuit of TWIN T-Oscillator. (Dec 2004, May 2005)

Refer figure 2.37.

12. Define Tuned collector oscillation.

Tuned collector oscillation is a type of transistor LC oscillator where the tuned circuit (tank) consists of a transformer and a capacitor is connected in the collector circuit of the transistor.

13. List out the Advantages and Disadvantages of RC Oscillators. (May/June 2008)

Advantages of RC phase shift oscillator

a) It provides good frequency stability.

b) The output is sinusoidal that is quite distortion free.

c) They have a wide frequency range (from a few Hz to several hundred kHz).

Disadvantages of RC phase shift oscillator

a) The output is small. It is due to smaller feedback.

b) It is difficult for the circuit to start oscillations as the feedback is usually small.

14. Define Piezo-electric Effect. (May/June 2006)

When a voltage source is applied to a small thin piece of quartz crystal, it begins to change shape producing a characteristic known as the Piezo-electric effect. This Piezo-electric Effect is the property of a crystal.

15. Give the equivalent circuit of quartz crystal and mention its series and parallel resonance frequency. (Dec 2005, May/June 2007, 2008, 2009, 2014)

Refer figure 2.38

16. What is the principle behind operation of crystal oscillator? (Nov/Dec 2007)

Refer section 2.16

17. Why LC oscillators does not produce sustained oscillations. How can this be overcome? (Dec 2008)

Due to certain losses in LC circuit, amplitude of oscillation goes on decreasing and finally oscillations stop. So LC oscillator does not produce sustained oscillation. If overall gain is increased, to overcome sustained stopping of sustained oscillations.

18. Draw a Miller oscillator circuit. (May 2005, Dec 2009)

Refer figure 2.43

19. State range of LC and RC oscillators. (May 2003)

Refer section 2.15

20. Define the frequency stability of oscillator. (May/June 2009)

The frequency stability of an oscillator is a measure of its ability to maintain as nearly a fixed frequency as possible over as long a time interval as possible.

21. What is the major disadvantages of Twin-T oscillator. (Dec 2012)

It is operated only at one frequency so this oscillator is not used rarely.

22. What is the necessary condition for a wien bridge oscillator to have sustained oscillations? (May 2013)

Gain of the amplifier must be at least 3 for oscillations to start. and phase shift of feedback circuit must be 00.

23. Write down the general applications of oscillators.

a) As a local oscillator in radio receivers

b) In TV receivers

c) In signal generators.

REVIEW QUESTIONS

1. Draw the circuit diagram and explain the operation of a RC phase shift oscillator. Describe the phase shift network and amplifier gain requirements. Derive the expression for frequency of operation of the circuit.
2. What is the principle of oscillation of crystals? Sketch the equivalent circuit and impedance-frequency graph of crystals and obtain its series and parallel resonant frequency.
3. Explain how crystals are employed in oscillators for stabilization.
4. Draw the circuit diagram of Colpitts oscillator. Derive the frequency of oscillation and condition for oscillation.
5. Draw the circuit diagram of a Wien Bridge oscillator and explain its working principle.
6. Draw the electrical equivalent circuit of the crystal and explain. Sketch its frequency response characteristics.
7. Explain how conditions for oscillation are satisfied for RC-phase shift oscillator and derive its frequency of oscillation.
8. What is the drawback of Colpitt oscillator and how it is overcome in Clapp oscillator? Draw the equivalent circuit of Clapp oscillator and derive its frequency of oscillation.