Chapter.7: Oscillators

- **Objectives:**
    - To understand
- The basic operation of an Oscillator
- the working of low frequency oscillators
        - –RC phase shift oscillator
        - –Wien bridge Oscillator
- the working of tuned oscillator
    - Colpitt’s Oscillator, Hartley Oscillator
    - Crystal Oscillator
- the working of UJT Oscillator

Basic operation of an Oscillator

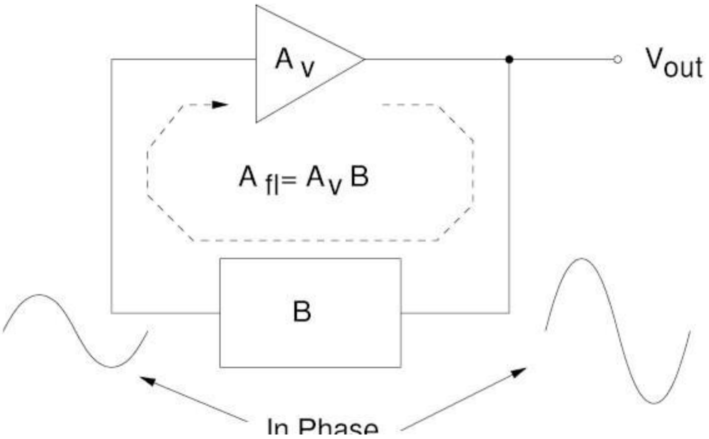
- An amplifier with positive feedback results in oscillations if the following conditions are satisfied:

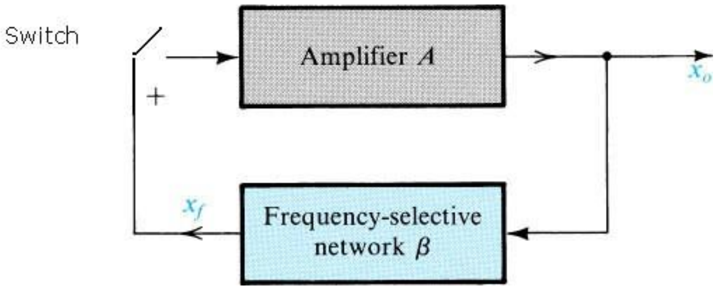
– The loop gain (product of the gain of the amplifier and the gain of the feedback network) is unity

– The total phase shift in the loop is 0°

- If the output signal is sinusoidal, such a circuit is referred to as sinusoidal

oscillator.





When the switch at the amplifier input is open, there are no oscillations. Imagine that a voltage Vi is fed to the circuit and the switch is closed. This results in Vo = AV Vi and

βVo = Vf is fed back to the circuit. If we make Vf = Vi, then even if we remove the input

voltage to the circuit, the output continues to exist.

Vo = AV Vi

βVo = Vf

β AV Vi = Vf

If Vf has to be same as Vi, then from the above equation, it is clear that, β AV =1.

Thus in the above block diagram, by closing the switch and removing the input, we are able to get the oscillations at the output if β AV =1, where β AV is called the Loop gain.

Positive feedback refers to the fact that the fed back signal is in phase with the input signal. This means that the signal experiences 0° phase shift while traveling in the loop.

The above condition along with the unity loop gain needs to be satisfied to get the sustained oscillations. These conditions are referred to as ‘Barkhausen criterion’. Another way of seeing how the feedback circuit provides operation as an oscillator is obtained by noting the denominator in the basic equation

$Af = A / (1+\beta A)$.

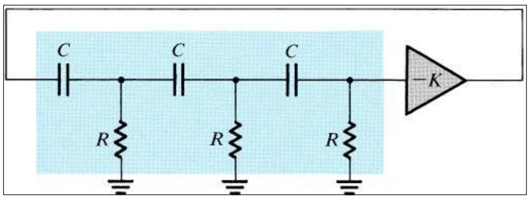
When $\beta A = -1$ or magnitude 1 at a phase angle of 180°, the denominator becomes 0 and

the gain with feedback Af becomes infinite.Thus, an infinitesimal signal (noise voltage)

can provide a measurable output voltage, and the circuit acts as an oscillator even without

an input signal.

Phase shift oscillator

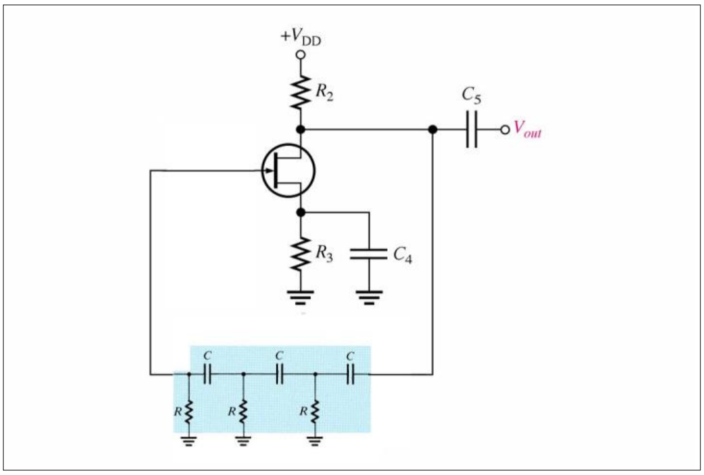


- The phase shift oscillator utilizes three RC circuits to provide 180º phase shift that when coupled with the 180º of the op-amp itself provides the necessary feedback to sustain oscillations.

- The gain must be at least 29 to maintain the oscillations. The frequency of resonance for the this type is similar to any RC circuit oscillator:

$fr = 1/2\surd\pi 6RC$

FET phase shift oscillator

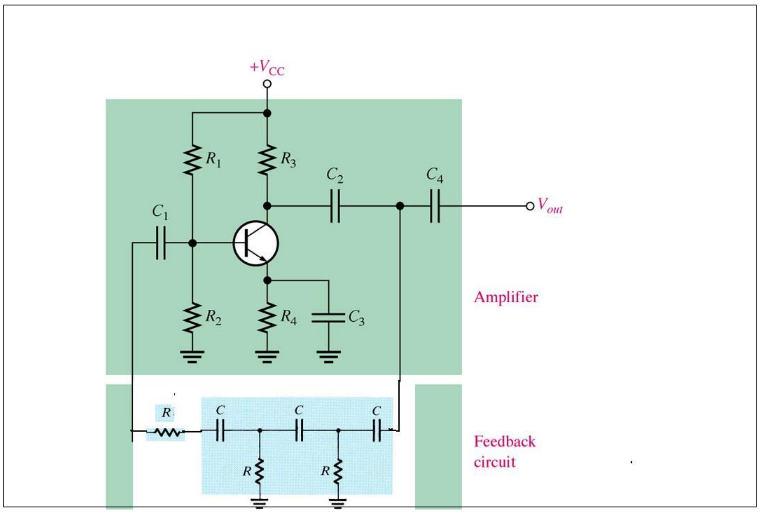


- The amplifier stage is self biased with a capacitor bypassed source resistor Rs and a drain bias resistor RD . The FET device parameters of interest are gm and rd.
- $|A| = gmRL$, where $RL = (RDrd / RD + rd)$
- At the operating frequency, we can assume that the input impedance of the

amplifier is infinite.

- This is a valid approximation provided, the oscillator operating frequency is low enough so that FET capacitive impedances can be neglected.
- The output impedance of the amplifier stage given by RL should also be small compared to the impedance seen looking into the feedback network so that no attenuation due to loading occurs.

RC Phase shift Oscillator - BJT version



- If a transistor is used as the active element of the amplifier stage, the output of the feedback network is loaded appreciably by the relatively low input resistance (

hie) of the transistor.

- An emitter – follower input stage followed by a common emitter amplifier stage

could be used.If a single transistor stage is desired, the use of voltage – shunt feedback is more suitable. Here, the feedback signal is coupled through the feedback resistor R’ in series with the amplifier stage input resistance (Ri).

$f = (1/2\pi RC)[1/\surd\, 6 + 4(RC / R)]$

hfe > 23 + 29 (R/RC) + 4 (RC / R)

Problem:

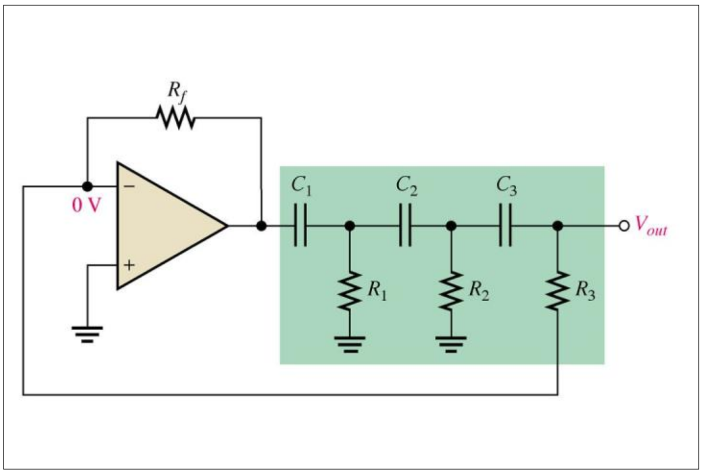
It is desired to design a phase shift oscillator using an FET having gm = 5000µS, rd = 40 kΩ , and a feedback circuit value of R = 10 kΩ. Select the value of C for oscillator operation at 5 kHz and RD for A > 29 to ensure oscillator action.

Solution:

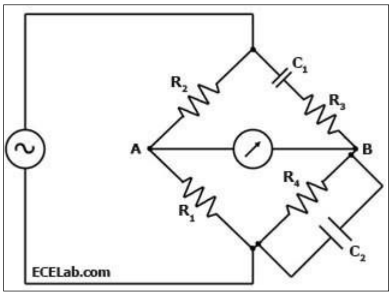
- f = 1/2√π6RC ; C = 1/2√π6Rf = 1.3nF
- |A| = gm RL

Let A = 40; RL = |A| / gm = 8 kΩ

IC phase shift Oscillator



Wien Bridge

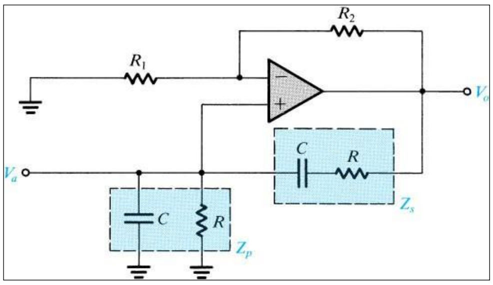


- When the bridge is balanced,

  $(R2 / R1) = (R3 / R4) + (C2 / C1)$

  $f = 1/[2\pi \sqrt{R3C1R4C2}]$

Wien bridge Oscillator

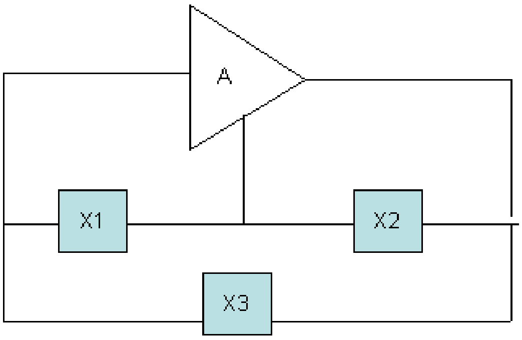


- R and C are used for frequency adjustment and resistors R1 and R2 form part of the feedback path.

- If R3 = R4 =R, C1 = C2 = C, the resulting frequency is $f = 1/2\pi RC$

and R2 / R1 = 2

Tuned Oscillators

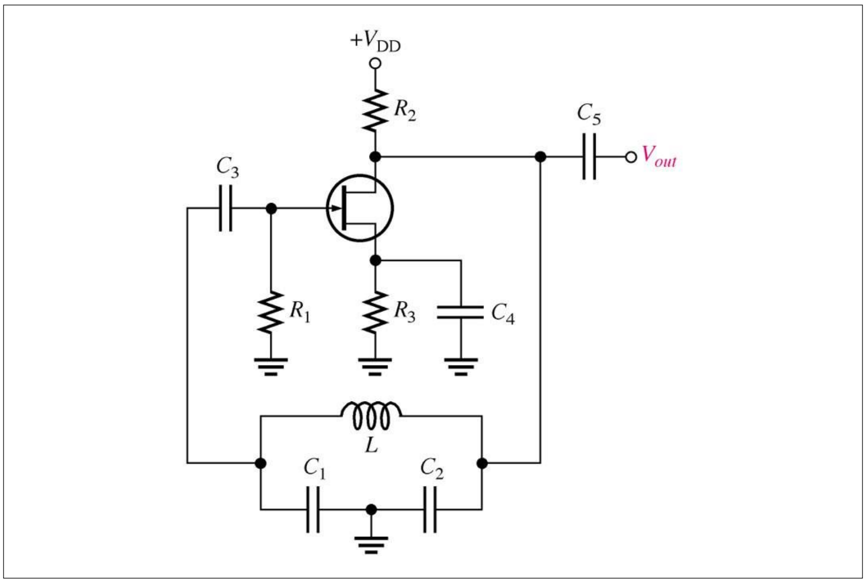


- A variety of circuits can be built using the above diagram, by providing tuning in both the input and output sections of the circuit.

- Analysis of the above diagram shows that the following types of Oscillators are obtained when the reactance elements are as designated:

Oscillator type	X1	X2	X3
Colpitts Oscillator	C	C	L
Hartley Oscillator	L	L	C
Tuned input, Tuned Output	LC	LC	-

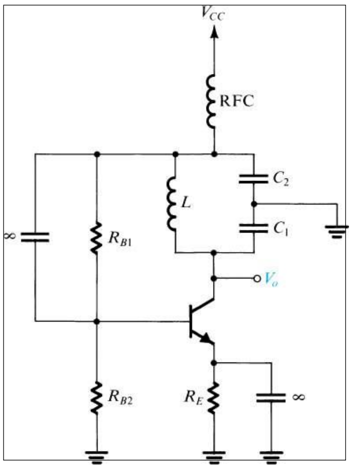
Colpitts Oscillator



- The Colpitts oscillator utilizes a tank circuit (LC) in the feedback loop. The resonant frequency can be determined by the formula below. Since the input impedance affects the Q, an FET is a better choice for the active device.

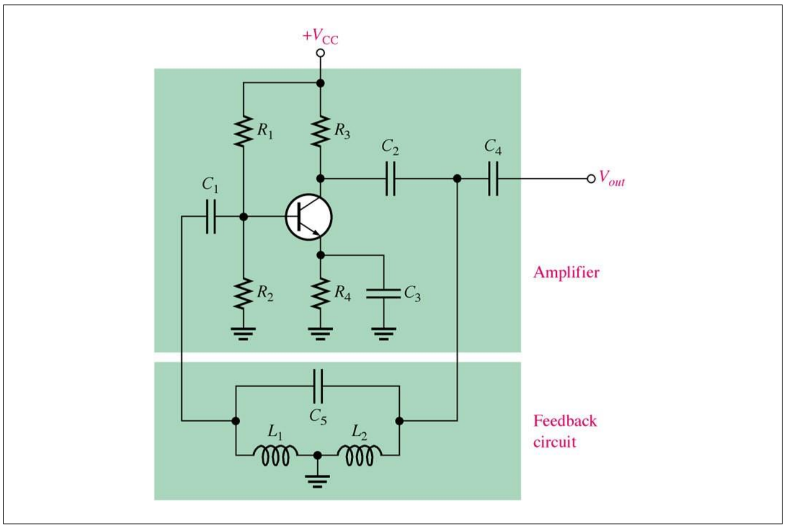
$fr = 1/2\surd\pi LCT$

$CT = C1C2 / C1 + C2$



- An Op amp Colpitts Oscillator circuit can also be used wherein the Op amp provides the basic amplification needed and the Oscillator frequency is set by an LC feedback network.

Hartley Oscillator

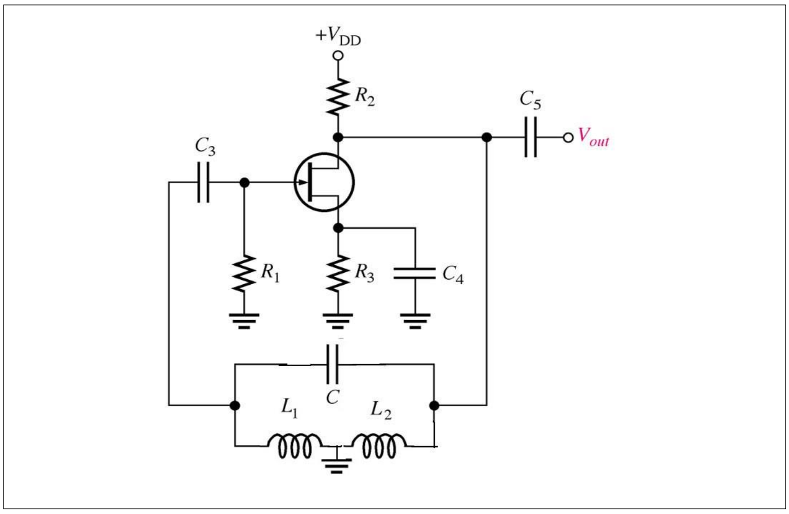


The Hartley oscillator is similar to the Colpitts. The tank circuit has two inductors and one capacitor. The calculation of the resonant frequency is the same.

$f = 1/2\surd\pi LTC$

$LT = L1 + L2 + 2M$

where, M is mutual coupling



Crystal Oscillator

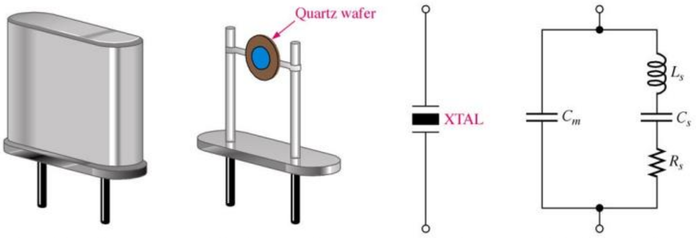
- A Crystal Oscillator is basically a tuned circuit Oscillator using a piezoelectric crystal as a resonant circuit.
- The crystal (usually quartz) has a greater stability in holding constant at whatever frequency the crystal is originally cut to operate.
- Crystal Oscillators are used whenever great stability is required, such as communication transmitters and receivers.

Characteristics of a Quartz Crystal

- A quartz crystal exhibits the property that when mechanical stress is applied across one set of its faces, a difference of potential develops across the opposite faces.
- This property of a Crystal is called ‘ Piezoelectric effect’.
- Similarly, a voltage applied across one set of faces of the Crystal causes mechanical distortion in the Crystal shape.
- When alternating voltage is applied to a crystal, mechanical vibrations are set up

– these vibrations having a natural resonant frequency dependent on the Crystal.

- Although the Crystal has electromechanical resonance, we can represent the Crystal action by equivalent electrical circuit as shown.



(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

- The inductor L and the capacitor C represent electrical equivalents of Crystal mass

and compliance respectively, whereas resistance R is an electrical equivalent of the crystal structures internal friction. The shunt capacitance CM represents the capacitance due to mechanical mounting of the crystal. Because the crystal losses, represented by R, are small, the equivalent crystal Q factor is high – typically 20,000. Values of Q up to almost 106 can be achieved by using Crystals. The Crystal can

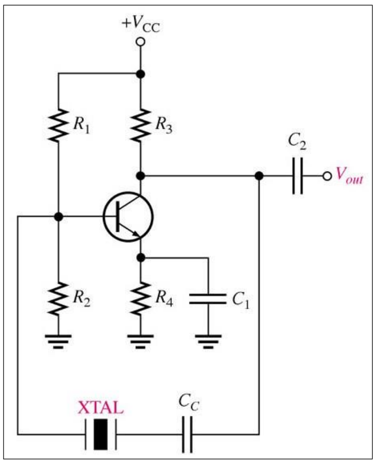
have two resonant frequencies. One resonant condition occurs when the reactances of the series RLC leg are equal. For this condition, the series – resonant impedance is very low (equal to R). The other resonant condition occurs at a higher frequency when the reactance of the series resonant leg equals the reactance of the capacitor CM. This is parallel resonance or antiresonance condition of the Crystal,

At this frequency, the crystal offers very high impedance to the external circuit. To use the crystal properly, it must be connected in a circuit so that its low impedance in the series resonant operating mode or high impedance in the antiresonant operating mode is selected.

Series resonant circuits

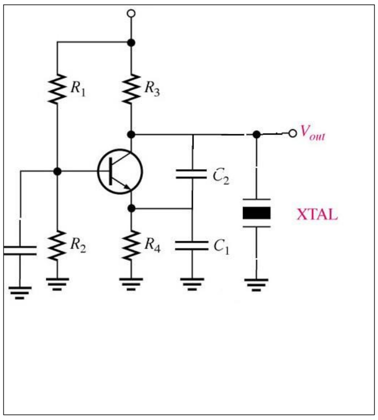
- To excite a crystal for operation in the series – resonant mode, it may be connected as a series element in a feedback path.

- At the series resonant frequency of the crystal, its impedance is smallest and the amount of feedback is largest.

- 

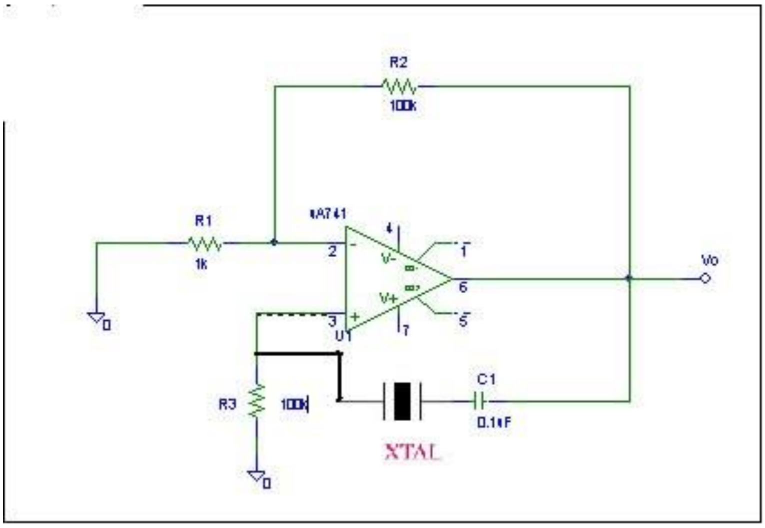
R3 can be replaced with RF choke. Resistors R1, R2 and RE provide a voltage divider stabililized dc bias circuit. Capacitor CE provides ac bypass of the emitter resistor, RFC coil provides for dc bias while decoupling any ac signal on the power lines from affecting the output signal. The voltage feedback from collector to base is a maximum when the crystal impedance is minimum (in series – resonant mode). The resulting circuit frequency of oscillation is set by the series – resonant frequency of the crystal. The circuit frequency stability is set by the crystal frequency stability which is good.

Parallel resonant circuits



Since the parallel resonant impedance of a crystal is a maximum value, it is connected in shunt. The circuit is similar to a Colpitts circuit with Crystal connected as inductor element. Maximum voltage is developed across the crystal at its parallel resonant frequency. The voltage is coupled to the emitter by a capacitor voltage divider capacitors C1 and C2.

Crystal Oscillator using op amp

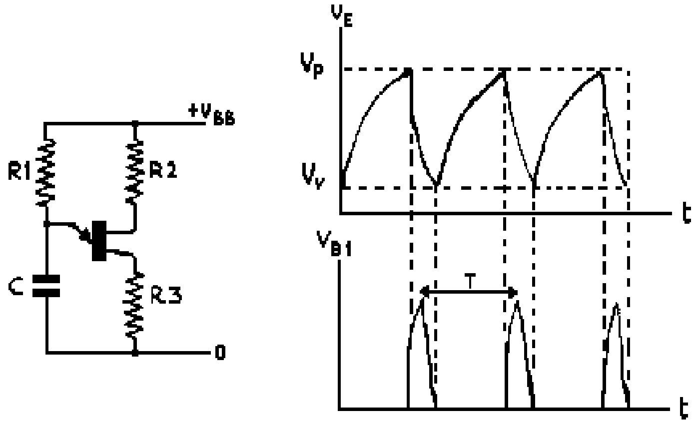


An Op – amp can be used in a crystal oscillator. The crystal is connected in the series resonant path and operates at the crystal series resonant frequency.

Unijunction Oscillator

Unijunction transistor (UJT) can be used in a single stage oscillator circuit to provide a pulse signal suitable for digital circuit applications. The UJT can be used in relaxation oscillator.

The operation of the circuit is as follows: C1 charges through R1 until the voltage across it reaches the peak point.



The emitter current then rises rapidly, discharging C1 through the base 1 region and R3. The sudden rise of current through R3 produces the voltage pulse. When the current falls to IV the UJT switches off and the cycle is repeated. Oscillator operating frequency fo = 1/{RTCTln[1/(1-η)]} where, η is

intrinsic standoff ratio, typically the value of it is between 0.4 and 0.6. Using η = 0.5, fo = 1.5 / RTCT

Capacitor is charged through resistor RT toward supply voltage VBB. As long as the capacitor voltage VE is below a stand – off voltage (VP) set by the voltage across

B1-B2 and the transistor stand – off ratio η.

- VP = ηVB1VB2 – VD.

When the capacitor voltage exceeds this value, the UJT turns ON, discharging the capacitor. When the capacitor discharges, a voltage rise is developed across R3.

The signal at the emitter of UJT / across the capacitor is saw tooth, at the base 1 are positive going pulses and at the base 2 are negative going pulses.

Summary:

- Phase shift Oscillator, $f = 1/2\pi RC\sqrt{6}$, $\beta = 1/29$
- Wien bridge Oscillator $f = 1/2\pi RC$
- Colpitts Oscillator, $f = 1/2\pi \sqrt{LCeq}$
- $Ceq = C1C2/(C1+C2)$
- Hartley Oscillator, $f = 1/2\pi \sqrt{LeqC}$
- $Leq = L1+L2+2M$
- UJT Oscillator: $f = 1/\{RTCT\ln[1/(1-\eta)]\}$