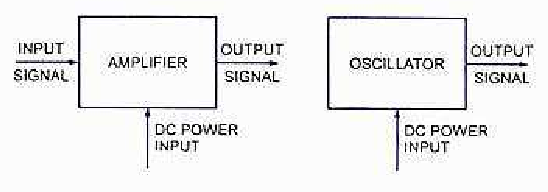
OSCILLATORS

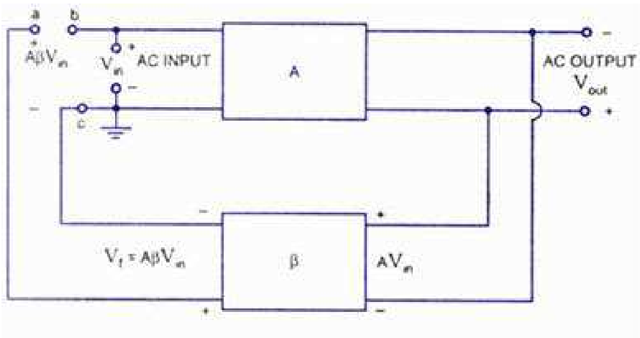
OSCILLATORS

- An oscillator can be described as a source of alternating voltage.
- An amplifier delivers an amplified version of input signal while oscillator generates an output waveform without an input signal.
- The additional power content in the output signal is supplied by an external DC power source.
- The oscillator requires no external signal to initiate or maintain the energy conversion process.
- Instead, an output signal is produced as long as a DC power source is connected.



PRINCIPLES OF OSCILLATORS

- Oscillators are amplifiers with positive feedback.
- Consider a feedback amplifier with an input signal V_{in} and output V_o as shown in the figure below.



- A is the open loop gain of the amplifier.
- Without feedback, output voltage of amplifier is

$$V_0 = A \text{ x } V_{in}$$

- Since positive feedback is used, feedback voltage V_f is added with input signal V_{in}
- Thus the input to the amplifier is $V_{in} + V_f$
- With feedback, the output voltage $V_o = A (V_{in} + V_f)$

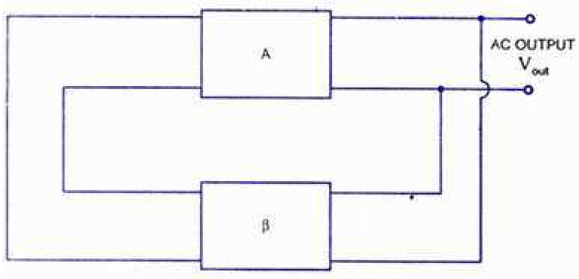
$$V_o = A (V_{in} + \beta V_o) \text{ because } V_f = \beta V_o$$

$$V_0 (1 - A\beta) = Av_{in}$$

$$\frac{V_o}{V_{in}} = \frac{A}{1 - A\beta}$$

- Which denotes the gain of the amplifier with feedback.

- Consider the case when the input signal V_{in} is removed and V_f is directly connected to the amplifier.



- This is the case of an oscillator that no input signal is applied to it.
- Then the condition for a non - zero output to exist can be derived from the equation $V_o / V_{in} = A / (1-A\beta)$, which is $V_{in}= 0$ (since there is no input for an oscillator) and V_o should be non zero.

- So for $V_o(1-A\beta) = 0$, then $A\beta$ must be equal to 1.
- Then the gain with feedback (closed loop gain) becomes infinite.
- Loop gain $A\beta$ =1 implies that

$$|A\beta| = 1$$
$$\angle A\beta = 0$$

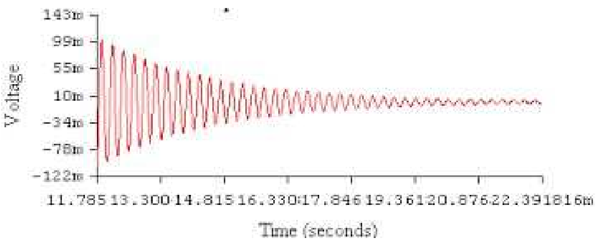
- Thus the conditions for sustained oscillations are

1. The magnitude of the loop gain $A\beta$ of the circuit must be equal to unity.
2. The phase shift of the loop gain $A\beta$ around the circuit must be 0 or 360^0

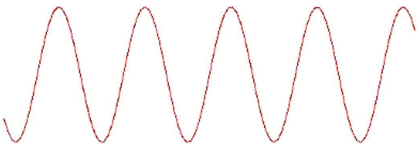
- These requirements are known as Barkhausen criteria.
- Barkhausen Criterion: A linear system will produce sustained oscillations only at frequencies for which the gain around the feedback loop is 1 and the phase shift around the feedback loop is ZERO or an integral multiple of 2π.

- The criterion $A\beta = 1$ is satisfied only at one frequency.
- Oscillations will not be sustained if $A\beta < 1$ or $A\beta > 1$
- Figure below shows the output for $A\beta < 1$ and $A\beta > 1$

- $A\beta < 1$

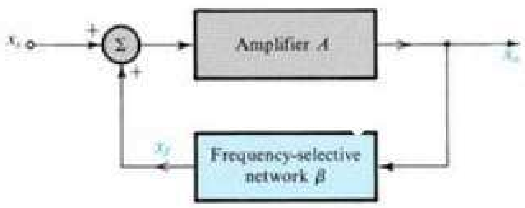


$A\beta = 1$



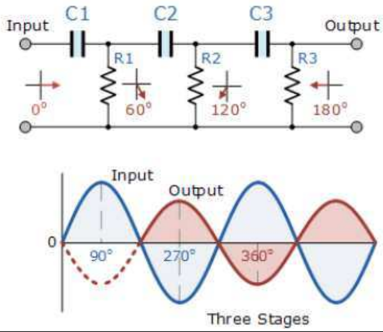
$A\beta > 1$

- If $A\beta$ is less than unity $A\beta V_{in}$ is less than V_{in} and the output signal will die out.
- If $A\beta > 1$, then $A\beta V_{in}$ is greater than V_{in} and the output voltage builds up gradually.
- If $A\beta = 1$, then the output voltage is sine wave under steady state conditions.
- Block diagram for an oscillator is shown in the figure below.



- It consists of an amplifier to maintain the loop gain at unity and a frequency selective network to determine the frequency of oscillation.

- Passive components normally determine the frequency of oscillation.
- They also influence stability, which is a measure of change in output frequency with time, temperature or other factors.
- Passive devices may include resistors, inductors, capacitors, transformers and resonant crystals.
- An RC phase shift network which offers 180^0 phase shift is shown in the figure below.



- Oscillators are classified in terms of their
  - Output Waveform
  - Frequency Range
  - Components or circuit configuration
- If the output waveform is sinusoidal, it is called sinusoidal oscillator.
- Otherwise, it is called relaxation oscillator, which include square, triangular and sawtooth waveforms.
- Oscillators employ both active and passive components.
- The active components provide energy conversion mechanism.
- Typical active devices are BJT (Bipolar Junction Transistor), FET (Field Effect Transistor) etc.

CLASSIFICATION OF OSCILLATORS

- **Oscillators can be classified in a variety of different ways. Some of the more common classes are:**
  - **Operating frequency band (Audio, Radio).**
  - **Output waveform (Sine wave, Square wave, Triangle wave, Sawtooth wave).**
  - **Components used to set the frequency (RC, LC, crystal).**
  - **Configuration of those components (Phase Shift, Wein Bridge, Hartley, Colpitts).**
  - **Purpose of the oscillator (Local oscillator, Beat Frequency oscillator, system clock, signal generator, function generator).**
  - **Available tuning range (fixed, adjustable, wide range).**
  - **Technology used (Analog, Digital, CMOS).**

OSCILLATOR OPERATION

- **The use of positive feedback that results in a feedback amplifier having closed-loop gain |Af | greater than 1 and satisfies the phase conditions will result in operation as an oscillator circuit.**
- **An oscillator circuit then provides a varying output signal.**
- **If the output signal varies sinusoidally, the circuit is referred to as a sinusoidal oscillator.**
- **If the output voltage rises quickly to one voltage level and later drops quickly to another voltage level, the circuit is generally referred to as a pulse or square-wave oscillator.**

- To understand how a feedback circuit performs as an oscillator, consider the feedback circuit of Fig. 18.18.

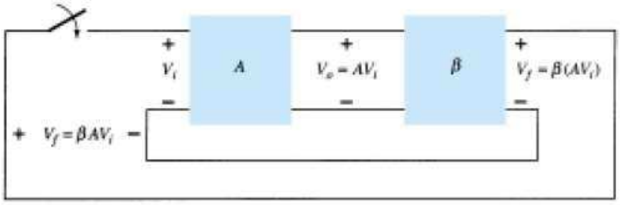


Figure 18.18 Feedback circuit used as an oscillator.

- When the switch at the amplifier input is open, no oscillation occurs.
- Consider that we have a fictitious voltage at the amplifier input (V_i).
- This results in an output voltage Vo $= AV_i$ after the amplifier stage and in a voltage $V_f = \beta$ (AVi) after the feedback stage.
- Thus, we have a feedback voltage $V_f = \beta AV_i$, where A is referred to as the loop gain.

- If the circuits of the base amplifier and feedback network provide *A* of a correct magnitude and phase, V_f can be made equal to *Vi*.
- Then, when the switch is closed and fictitious voltage *Vi* is removed, the circuit will continue operating since the feedback voltage is sufficient to drive the amplifier and feedback circuits resulting in a proper input voltage to sustain the loop operation.
- The output waveform will still exist after the switch is closed if the condition $A\beta = 1$, is met.
- This is known as the *Barkhausen criterion* for oscillation.
- In reality, no input signal is needed to start the oscillator going.
- Only the condition $A\beta = 1$ must be satisfied for self-sustained oscillations to result.
- In practice, $A\beta$ is made greater than 1 and the system will start oscillating by amplifying noise voltage, which is always present.

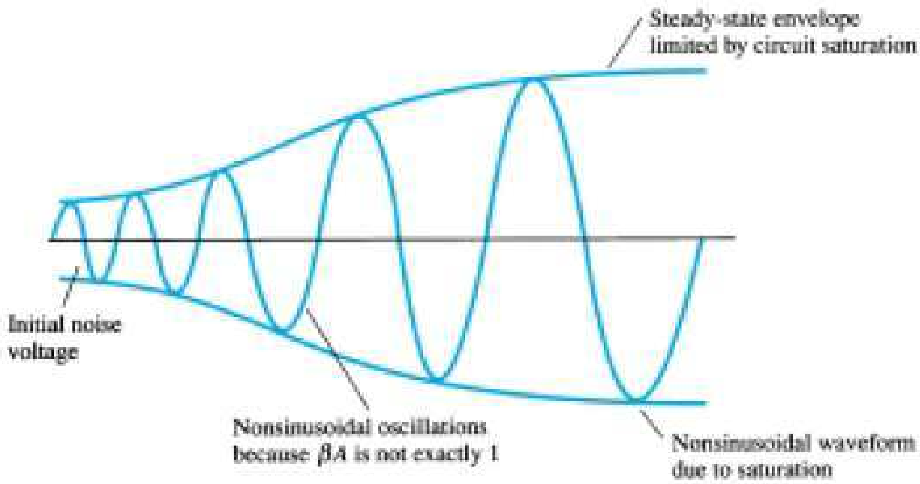


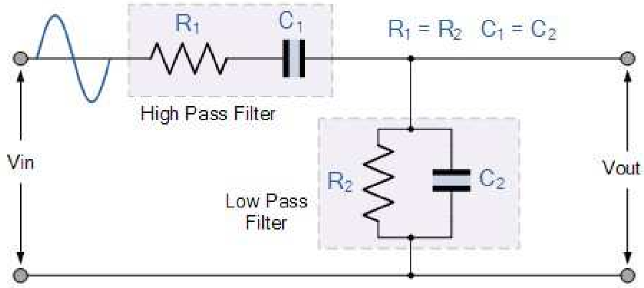
Figure 18.19 Buildup of steady-state oscillations.

WIEN BRIDGE OSCILLATOR

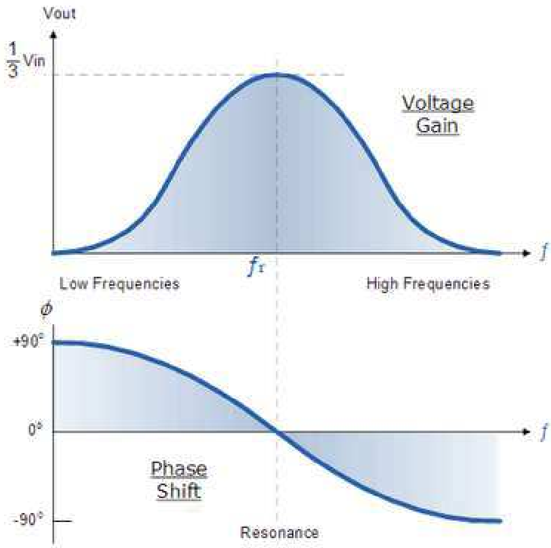
WIEN BRIDGE OSCILLATOR

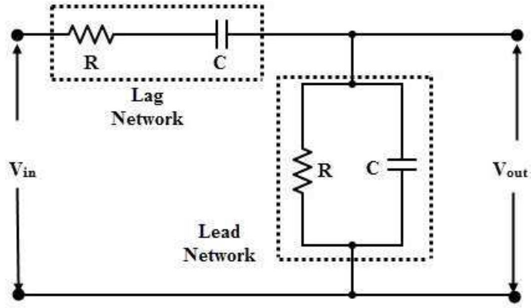
- **The Wien Bridge Oscillator is so called because the circuit is based on a frequency-selective form of the Wheatstone bridge circuit.**
- **The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune, making it a popular circuit as an audio frequency oscillator.**
- **This type of oscillator is simple in design, compact in size, and remarkably stable in its frequency output.**
- **This type of oscillator uses RC feedback network so it can also be considered as RC oscillator.**

- **The Wien Bridge Oscillator uses a feedback circuit consisting of a series RC circuit connected with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency.**
- **At the resonant frequency f_r the phase shift is 0^o.**
- **Consider the circuit below.**



- **At low frequencies the reactance of the series capacitor (C_1) is very high so acts a bit like an open circuit, blocking any input signal at Vin resulting in virtually no output signal, V_{out}.**
- **Likewise, at high frequencies, the reactance of the parallel capacitor, (C_2) becomes very low, so this parallel connected capacitor acts a bit like a short circuit across the output, so again there is no output signal.**
- **So there must be a frequency point between these two extremes of C_1 being open-circuited and C_2 being short-circuited where the output voltage, V_{OUT} reaches its maximum value.**
- **The frequency value of the input waveform at which this happens is called the oscillators *Resonant Frequency*, (f_r).**
- **At this resonant frequency, the circuits reactance equals its resistance, that is: $X_c = R$, and the phase difference between the input and output equals zero degrees.**
- **The magnitude of the output voltage is therefore at its maximum and is equal to one third (1/3) of the input voltage as shown below.**





At Resonance, R = X_C

$$R = \frac{1}{2\pi f_r C}$$

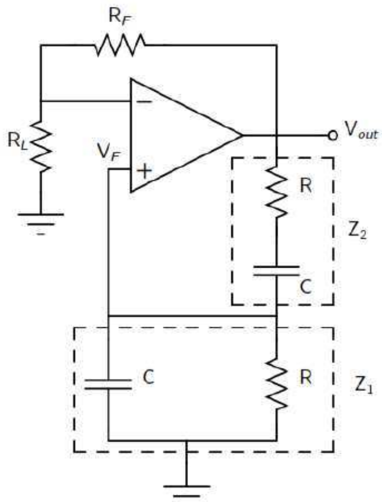
$$f_r = \frac{1}{2\pi R C}$$

Wien Bridge Oscillator Frequency

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

Where:
f_r is the Resonant Frequency in Hertz
R is the Resistance in Ohms
C is the Capacitance in Farads

MATHEMATICAL ANALYSIS



The feedback voltage V_f is given by,

$$V_f = \frac{Z_1}{Z_1+Z_2} V_{out} \qquad (1)$$

where,

$$Z_1 = \frac{R}{1+RCS} \qquad (2)$$

$$Z_2 = R + \frac{1}{Cs} \qquad (3)$$

Substituting these values in Eq.1 we get,

$$V_f = \frac{\frac{R}{1+RCs}}{\frac{R}{1+RCs} + R + \frac{1}{Cs}} V_{out}$$

Substituting the value of s=jω and simplifying we get,

$$V_f = \frac{j\omega CR}{1+3RCj\omega - C^2 R^2 \omega^2} V_{out}$$

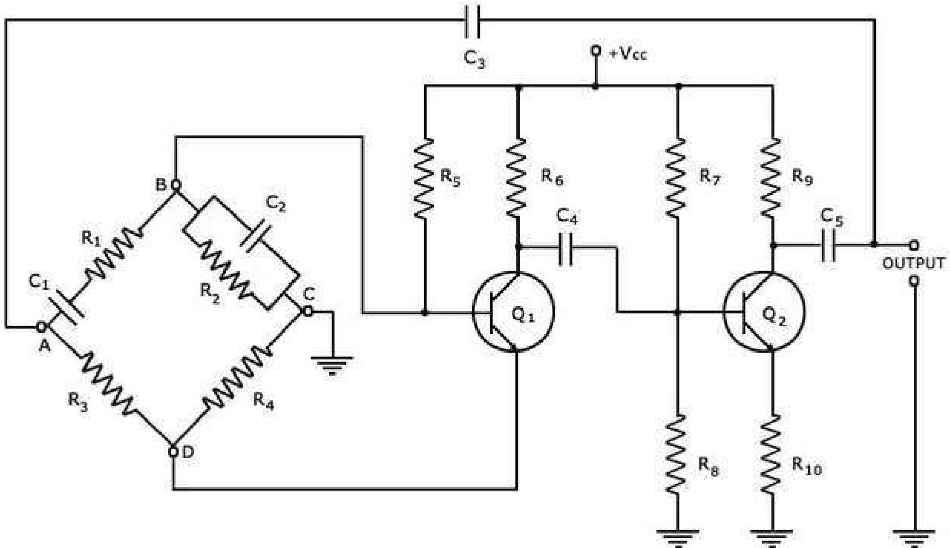
To ensure phase shift of 0^0 by the feedback network,

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

This leads to $\omega = \frac{1}{RC} \Rightarrow f = \frac{1}{2\pi RC}$

This happens for $V_f = \frac{V_{out}}{3}$

- **The circuit diagram of Wien bridge oscillator is shown in the figure below.**



- **It is essentially a two-stage amplifier with an R-C bridge circuit.**
- **R-C bridge circuit (Wien bridge) is a lead-lag network.**
- **The phase'-shift across the network lags with increasing frequency and leads with decreasing frequency.**
- **By adding Wien-bridge feedback network, the oscillator becomes sensitive to a signal of only one particular frequency.**
- **This particular frequency is that at which Wien bridge is balanced and for which the phase shift is 0°.**
- **If the Wien-bridge feedback network is not employed and output of transistor Q_2 is fedback to transistor Q_1 for providing regeneration required for producing oscillations, the transistor Q_1 will amplify signals over a wide range of frequencies and thus direct coupling would result in poor frequency stability.**
- **Thus by employing Wien-bridge feedback network frequency stability is increased.**

- **This bridge circuit can be used as feedback network for an oscillator, provided that the phase shift through the amplifier is zero.**
- **The two transistors Q_1 and Q_2 causes a total phase shift of 360° and ensure proper positive feedback.**
- **The feedback network has an attenuation of 1/3.**
- **Thus, in this case, voltage gain A, must be equal to or greater than 3, to sustain oscillations.**
- **<u>WORKING</u>**
- **The circuit is set in oscillation by any random change in base current of transistor Q_1, that may be due to noise inherent in the transistor or variation in voltage of dc supply.**
- **This variation in base current is amplified in collector circuit of transistor Q_1 but with a phase-shift of 180°, the output of transistor Q_1 is fed to the base of second transistor Q_2 through capacitor C_4.**

- Now a still further amplified and twice phase-reversed signal appears at the collector of the transistor Q_2.
- Having been inverted twice, the output signal will be in phase with the signal input to the base of transistor Q_1.
- A part of the output signal at transistor Q_2 is fedback to the input points of the bridge circuit (point A-C).
- A part of this feedback signal is applied to emitter resistor R_4 where it produces degenerative effect (or negative feedback).
- Similarly, a part of the feedback signal is applied across the base-bias resistor R_2 where it produces regenerative effect (or positive feedback).
- At the rated frequency, effect of regeneration is made slightly more than that of degeneration so as to obtain sustained oscillations.
- We can change the frequency range of the oscillator by switching into the circuit different values of resistors R_1 and R_2.

- **Advantages**

1. Provides a stable low distortion sinusoidal output over a wide range of frequency.
2. The frequency range can be selected simply by using decade resistance boxes.
3. The frequency of oscillation can be easily varied by varying capacitances C_1 and C_2 simultaneously.
4. The overall gain is high because of two transistors.

- **Disadvantages**

1. The maximum frequency output of a typical Wien bridge oscillator is only about 1 MHz.
2. The circuit needs two transistors and a large number of other components.
3. The maximum frequency output is limited because of amplitude and the phase-shift characteristics of amplifier.

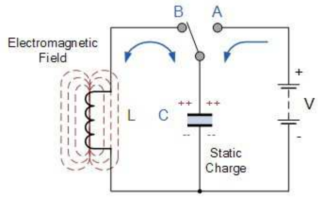
HARTLEY OSCILLATOR

LC OSCILLATOR RESONANCE

- **At high frequencies the reactance of a capacitor is very low, acting as a short circuit while the reactance of the inductor is high acting as an open circuit.**
- **At low frequencies the reverse is true, the reactance of the capacitor acts as an open circuit and the reactance of the inductor acts as a short circuit.**
- **Between these two extremes the combination of the inductor and capacitor produces a "Tuned" or "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.**

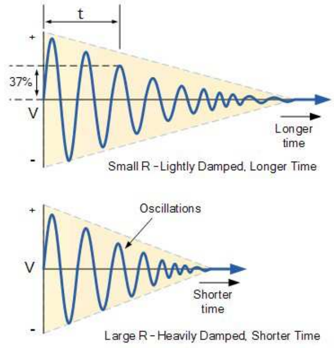
BASIC LC OSCILLATOR TANK CIRCUIT

- Consider the circuit below.
- The circuit consists of an inductive coil, L and a capacitor, C.
- 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 magnetic field.
- The capacitor is charged up to the DC supply voltage, V by putting the switch in position A.
- When the capacitor is fully charged the switch changes to position B.



- 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 a magnetic 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 a magnetic field around the coils windings.
- As there is now no external voltage in the circuit to maintain the current within the coil, it starts to fall as the magnetic field begins to collapse.

- This process then forms the basis of an LC oscillators tank circuit and theoretically this cycling back and forth will continue indefinitely.
- However, things are not perfect and 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.



RESONANCE FREQUENCY

$$X_L = 2\pi f L \quad \text{and} \quad X_C = \frac{1}{2\pi f C}$$

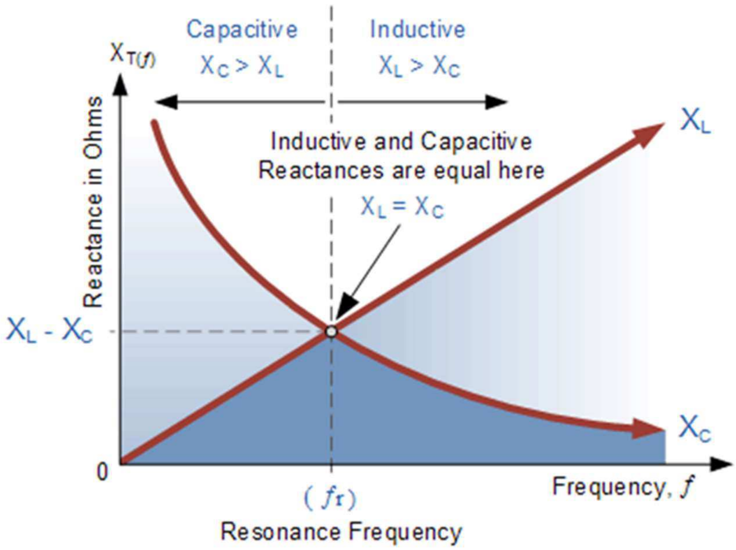
$$\text{at resonance:} \quad X_L = X_C$$

$$\therefore \; 2\pi f L = \frac{1}{2\pi f C}$$

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

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

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



Resonant Frequency of a LC Oscillator

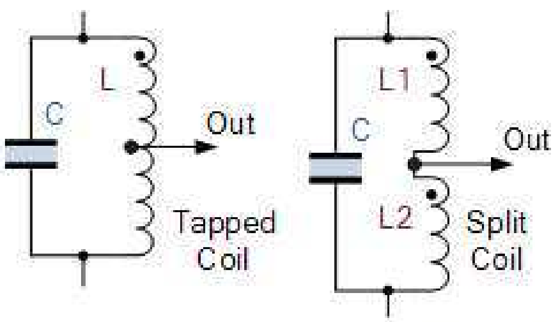
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

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".
- 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.
- If the energy replaced is too large the amplitude would increase until clipping of the supply rails occurs.
- Alternatively, if the amount of energy replaced is too small the amplitude would eventually decrease to zero over time and the oscillations would stop.

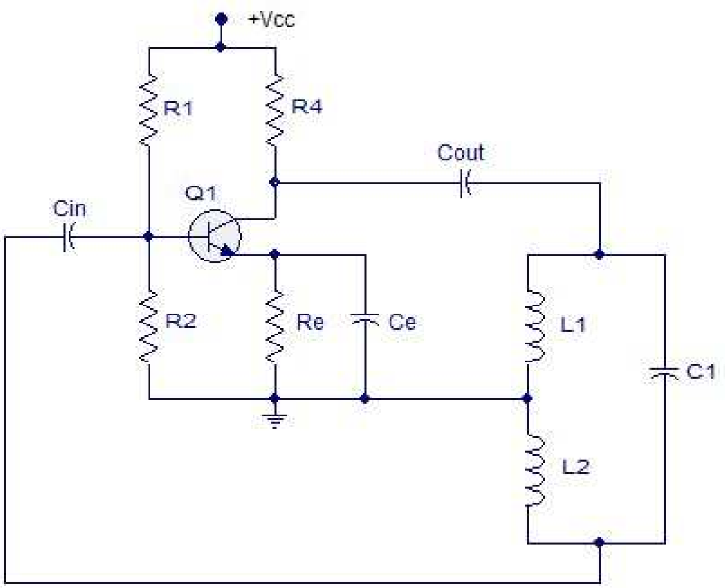
HARTLEY OSCILLATOR

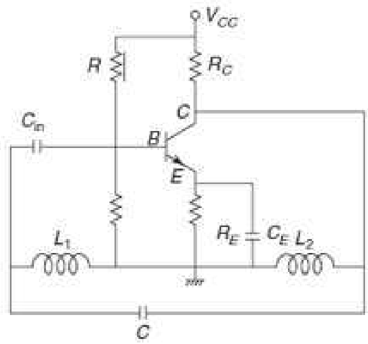
- The Hartley Oscillator design uses two inductive coils in series with a parallel capacitor to form its resonance tank circuit and produce sinusoidal oscillations.



Hartley Oscillator Tank Circuit

- In a Hartley oscillator the oscillation frequency is determined by a tank circuit comprising of two inductors and one capacitor.
- The inductors are connected in series and the capacitor is connected across them in parallel.
- Hartley oscillators are commonly used in radio frequency (RF) oscillator applications and the recommended frequency range is from 20KHz to 30MHz.
- The circuit diagram of a typical Hartley oscillator is shown in the figure below.





- **In the circuit diagram resistors R_1 and R_2 give a potential divider bias for the transistor Q_1.**
- **R_e is the emitter resistor, whose job is to provide thermal stability for the transistor.**
- **C_e is the emitter by pass capacitor, which by-passes the amplified AC signals.**
- **If the emitter by-pass capacitor is not there, the amplified ac voltages will drop across R_e and it will get added on to the base-emitter voltage of Q_1 and will disrupt the biasing conditions.**
- **C_{in} is the input DC decoupling capacitor while C_{out} is the output DC decoupling capacitor.**
- **The task of a DC decoupling capacitor is to prevent DC voltages from reaching the succeeding stage.**
- **Inductor L_1, L_2 and capacitor C_1 forms the tank circuit.**

- **When the power supply is switched ON the transistor starts conducting and the collector current increases.**
- **As a result the capacitor C_1 starts charging and when the capacitor C_1 is fully charged it starts discharging through coil L_1.**
- **This charging and discharging creates a series of damped oscillations in the tank circuit and it is the key.**
- **The oscillations produced in the tank circuit is coupled (fed back) to the base of Q_1 and it appears in the amplified form across the collector and emitter of the transistor.**
- **The output voltage of the transistor (voltage across collector and emitter) will be in phase with the voltage across inductor L_1.**
- **Since the junction of two inductors is grounded, the voltage across L_2 will be 180° out of phase to that of the voltage across L_1.**

- **The voltage across L_2 is actually fed back to the base of Q_1.**
- **From this we can see that, the feed back voltage is 180° out of phase with the transistor and also the transistor itself will create another 180° phase difference.**
- **So the total phase difference between input and output is 360° and it is very important condition for creating sustained oscillations.**
- **Barkhausen Criterion: A linear system will produce sustained oscillations only at frequencies for which the gain around the feedback loop is 1 and the phase shift around the feedback loop is ZERO or an integral multiple of 2π.**
- **The frequency of oscillation can be calculated in the same way as any parallel resonant circuit, using:**

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

Where $L = L_1 + L_2$

- **This basic formula is adequate where the mutual inductance between L_1 and L_2 is negligible, but needs to be modified when the mutual inductance between L_1 and L_2 is considerable.**
- **Mutual inductance is an additional effective amount of inductance caused by the magnetic field created around one inductor (or one part of a tapped inductor) inducing a current into the other inductor.**
- **When both inductors are wound on a common core, the effect of mutual inductance (M) can be considerable and the total inductance is calculated by the formula:**

$$L_{TOT} = L_1 + L_2 \pm 2M$$

- **The actual value of M depends on how effectively the two inductors are magnetically coupled, which among other factors depends on the spacing between the inductors, the number of turns on each inductor, the dimensions of each coil and the material of the common core.**

SUMMARY

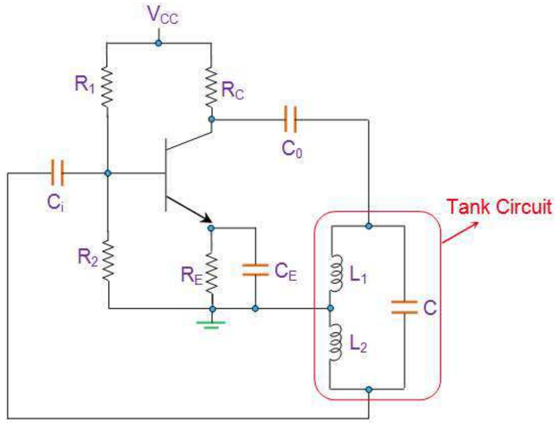


Figure 1 Hartley Oscillator

$$F = \frac{1}{2\pi\sqrt{L_{eff}C}}$$

Where,

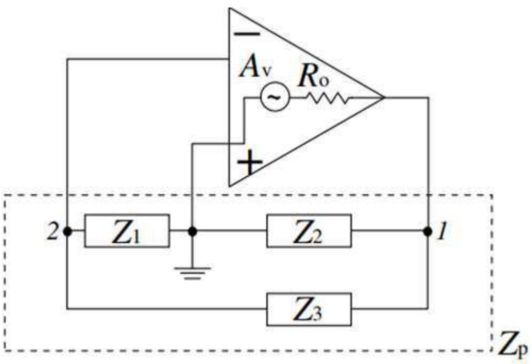
L_{eff} *is the effective series inductance which is expressed as*

$L_{eff} = L_1 + L_2$; *if the coils are wound on different cores*

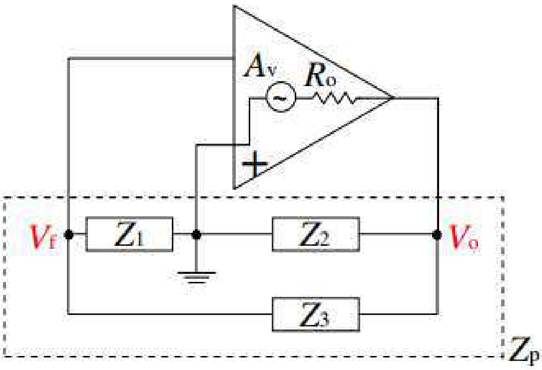
$L_{eff} = L_1 + L_2 + 2M$; *if the coils are wound on the same core*

MATHEMATICAL ANALYSIS

- **The frequency selection network (Z_1, Z_2 and Z_3) provides a phase shift of 180°**
- **Output voltage is developed across Z_2 and feedback voltage is developed across Z_1 .**
- **The amplifier provides additional shift of 180°**



Hartley—The resonant circuit is a tapped inductor or two inductors and one capacitor.

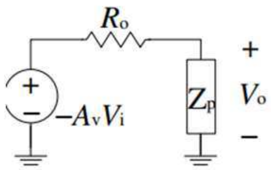


$$V_f = \beta V_o = \frac{Z_1}{Z_1 + Z_3} V_o$$

$$Z_p = Z_2 // (Z_1 + Z_3)$$

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

For the equivalent circuit from the output



$$\frac{-A_v V_i}{R_o + Z_p} = \frac{V_o}{Z_p} \quad \text{or} \quad \frac{V_o}{V_i} = \frac{-A_v Z_p}{R_o + Z_p}$$

Therefore, the amplifier gain is obtained,

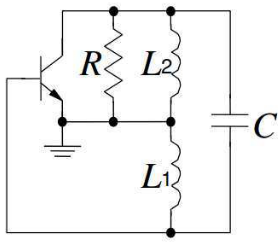
$$A = \frac{V_o}{V_i} = \frac{-A_v Z_2(Z_1 + Z_3)}{R_o(Z_1 + Z_2 + Z_3) + Z_2(Z_1 + Z_3)}$$

The loop gain,

$$\boxed{A\beta = \frac{-A_v Z_1 Z_2}{R_o(Z_1 + Z_2 + Z_3) + Z_2(Z_1 + Z_3)}}$$

Hartley Oscillator

$Z_1 = j\omega L_1$; $Z_2 = j\omega L_2$; $Z_3 = 1/j\omega C$



$$A\beta = \frac{A_v(\omega^2 L_1 L_2)}{j(\omega L_1 + \omega L_2 - 1/\omega C)R_o + \omega L_2(\omega L_1 + 1/\omega C)}$$

For ***Barkhausen Criterion*** $A\beta$=1, imaginary part = 0,

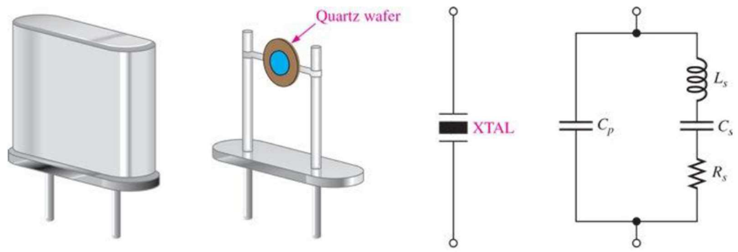
$$\omega L_1 + \omega L_2 = 1/\omega C$$

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

CRYSTAL OSCILLATOR

INTRODUCTION

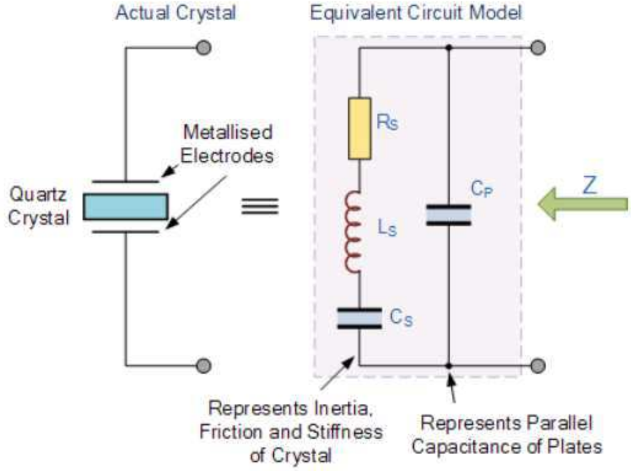
- Some of the factors that affect the frequency stability of an oscillator generally include: variations in temperature, variations in the load, as well as changes to its DC power supply voltage, to name a few.
- Frequency stability of the output signal can be greatly improved by the proper selection of the components used for the resonant feedback circuit, including the amplifier.
- But there is a limit to the stability that can be obtained from normal LC and RC tank circuits.
- 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).

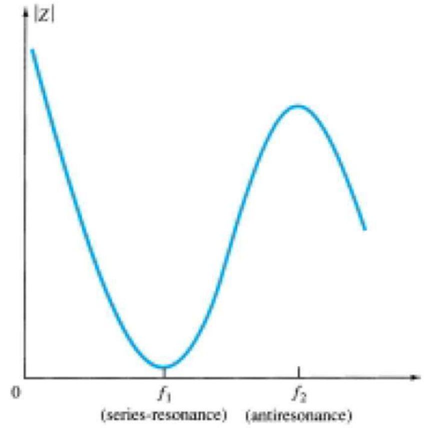


(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

- **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 by which an electrical charge produces a mechanical force by changing the shape of the crystal and vice versa, a mechanical force applied to the crystal produces an electrical charge.**
- **This piezo-electric effect produces mechanical vibrations or oscillations which can be used to replace the standard LC tank circuit in the previous oscillators.**
- **Its size and shape determines its fundamental oscillation frequency.**

QUARTZ CRYSTAL EQUIVALENT MODEL

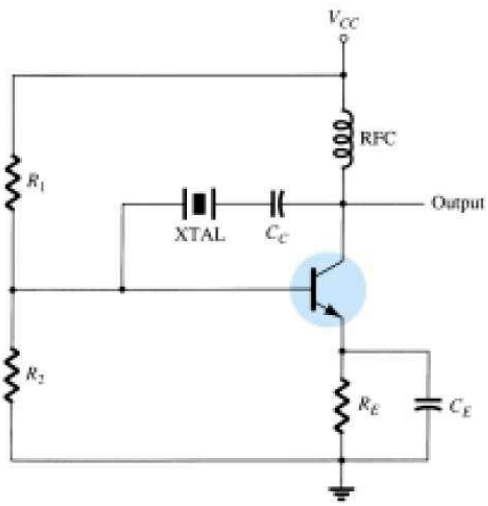




Crystal impedance versus frequency.

SERIES-RESONANT CIRCUITS

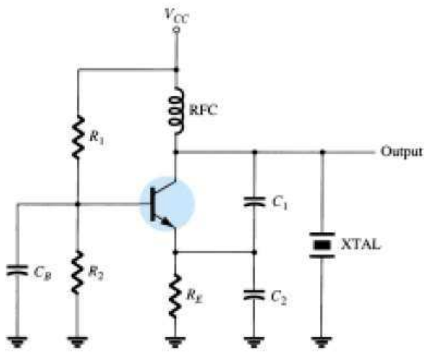
- **To excite a crystal for operation in the series-resonant mode, it may be connected as a series element in a feedback path.**
- **At the series-resonant frequency of the crystal, its impedance is smallest and the amount of (positive) feedback is largest.**
- **A typical transistor circuit is shown in Fig.**



- Resistors R_1, R_2, and R_E provide a voltage divider stabilized dc bias circuit.
- Capacitor C_E provides ac bypass of the emitter resistor, and the 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 coupling capacitor C_C has negligible impedance at the circuit operating frequency but blocks any dc between collector and base.
- The resulting circuit frequency of oscillation is set, then, by the series-resonant frequency of the crystal.
- Changes in supply voltage, transistor device parameters, and so on have no effect on the circuit operating frequency, which is held stabilized by the crystal.
- The circuit frequency stability is set by the crystal frequency stability, which is good.

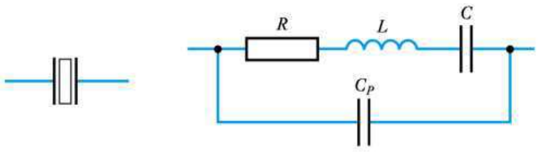
PARALLEL-RESONANT CIRCUITS

- Since the parallel-resonant impedance of a crystal is a maximum value, it is connected in shunt.
- At the parallel-resonant operating frequency, a crystal appears as an inductive reactance of largest value.
- Figure shows a crystal connected as the inductor element in a modified Colpitts circuit.
- The basic dc bias circuit should be evident.
- 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 *C*1 and *C*2.



MATHEMATICAL ANALYSIS

- A piezoelectric crystal exhibit electromechanical resonance characteristics.
- The resonance properties are characterized by large inductance L, a very small series capacitance C, and small series resistance R
- Generally $C_p >> C$



(a) Circuit symbol (b) Equivalent circuit

- Since the Q factor is very high, we may neglect R.

$$Z(j\omega) = Z_3 // (Z_1 + Z_2) = \frac{Z_3(Z_1 + Z_2)}{Z_1 + Z_2 + Z_3}$$

Where

$Z_1 = j\omega L$; $Z_2 = 1/j\omega C$; $Z_3 = 1/j\omega C_p$

$$Z(j\omega) = \frac{\frac{1}{j\omega C_p}\left(j\omega L + \frac{1}{j\omega C}\right)}{j\omega L + \frac{1}{j\omega C} + \frac{1}{j\omega C_p}}$$

$$= \frac{-j}{\omega C_p}\left[\frac{\frac{j^2\omega^2 LC + 1}{j\omega C}}{j\omega L + \frac{j\omega C_p + j\omega C}{(j\omega)^2 C C_p}}\right]$$

$$= \frac{-j}{\omega C_p}\left[\frac{\dfrac{-\omega^2 LC+1}{j\omega C}}{j\omega L + \dfrac{C_p+C}{j\omega C\cdot C_p}}\right]$$

$$= \frac{-j}{\omega C_p}\left[\frac{\dfrac{-\omega^2 LC+1}{j\omega C}}{\dfrac{j^2\omega^2 LC\cdot C_p + C(C_p+C)}{j\omega C\cdot C_p}}\right]$$

$$= \frac{-j}{\omega C_p}\left[\frac{-\omega^2 LC+1}{-\omega^2 LC + \dfrac{C_p+C}{C_p}}\right]$$

$\div$ numerator and denominator with $-LC$, we get

$$Z(j\omega) = \frac{-j}{\omega C_p}\left[\frac{\omega^2 - \dfrac{1}{LC}}{\omega^2 - \dfrac{C_p+C}{LCC_p}}\right]$$

Z(jω) will be the least when numerator is zero.
This gives the condition for series resonance as

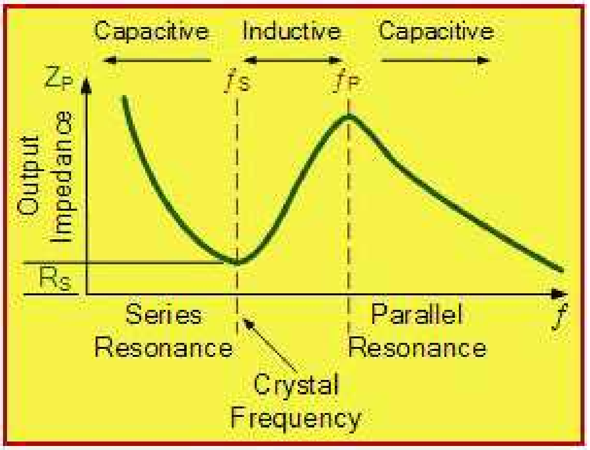
$$\omega_s^2 = \frac{1}{LC} \Rightarrow f_s = \frac{1}{2\pi\sqrt{LC}}$$

Z(jω) will be maximum when denominator is zero.
This gives the condition for parallel resonance

$$\omega_p^2 = \frac{1}{\frac{LCC_p}{C+C_p}} \Rightarrow f_p = \frac{1}{2\pi\sqrt{L\left(\frac{CC_p}{C+C_p}\right)}}$$

$$\boxed{Z(j\omega) = -j\frac{1}{\omega C_p}\left(\frac{\omega^2 - \omega_s^2}{\omega^2 - \omega_p^2}\right)}$$

Where $\boxed{\omega_s = \frac{1}{\sqrt{LC}}}$ $\boxed{\omega_P = \frac{1}{\sqrt{\frac{LCC_P}{(C+C_P)}}}}$



Impedance vs Frequency Graph

$$f_S = \frac{1}{2\pi\sqrt{L_S C_S}}$$

$$f_P = \frac{1}{2\pi\sqrt{L_S\left(\frac{C_P C_S}{C_P + C_S}\right)}}$$

Series Resonant Frequency and Parallel Resonant Frequency

MULTIVIBRATORS

INTRODUCTION

- **Multivibrators belong to a family of oscillators commonly called "Relaxation Oscillators".**
- **Clock pulses are generally continuous square or rectangular shaped waveform that is produced by a single pulse generator circuit such as a Multivibrator.**
- **A multivibrator circuit oscillates between a "HIGH" state and a "LOW" state producing a continuous output.**

TYPES OF MULTIVIBRATORS

- **There are basically three types of Multivibrator circuits:**
- **Astable – A free-running multivibrator that has NO stable states but switches continuously between two states this action produces a train of square wave pulses at a fixed frequency.**
- **Monostable – A one-shot multivibrator that has only ONE stable state and is triggered externally with it returning back to its first stable state.**
- **Bistable – A flip-flop that has TWO stable states that produces a single pulse either positive or negative in value.**

ASTABLE MULTIVIBRATOR

- **An Astable Multivibrator or a Free Running Multivibrator is the multivibrator which has no stable states.**
- **Its output oscillates continuously between its two unstable states without the aid of external triggering.**
- **The time period of each states are determined by Resistor Capacitor (RC) time constant.**
- **Regenerative switching circuits such as Astable Multivibrators are the most commonly used type of relaxation oscillator because not only are they simple, reliable and easy to construct, they also produce a constant square wave output waveform.**

- These circuits generally comprise of passive components like resistors and capacitors together with active elements which can be BJTs (Bipolar Junction Transistors) or FETs (Field Effect Transistors) or Op-Amps or 555 timer ICs.

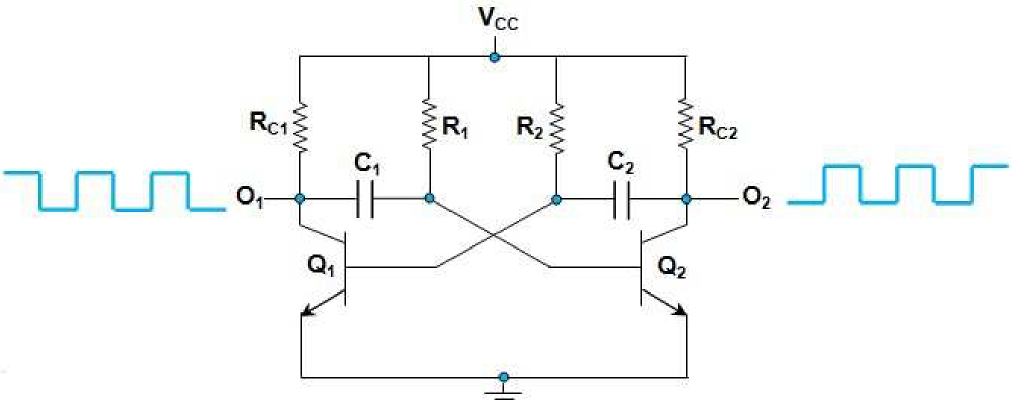


Figure 1 Astable Multivibrator Using BJTs

- It consists of two common emitter amplifying stages.
- The output of an astable multivibrator is available at the collector terminals of either transistor.
- However, the two outputs are out of phase with each other.
- In this kind of circuit, the application of the supply voltage V_{CC} causes one of the transistors to turn ON earlier than the other due to the inevitable difference in their electrical properties.
- Let us suppose that Q1 is On and Q2 is off.
- The circuit operation may be explained as follows.

1. Since transistor Q1 is in saturation, output O1 will be at zero potential.
2. Since Q2 is in cutoff,no current flows through Rc2 and hence O2 will be at Vcc.

3. **Since O2 is at 0V, capacitor C2 starts charging through R2 towards Vcc.**
4. **When the voltage across C2 rises sufficiently (i.e. more than 0.7V), it forward biases Q2 and it starts conducting.**
5. **O2 starts decreasing from Vcc to almost zero as Q2 saturates.**
6. **This potential decrease (negative swing) is applied to the base of Q1, driving it into cutoff.**
7. **Since now O1 is at 0V, capacitor C1 starts charging through R1 towards Vcc.**
8. **When the voltage across C1 rises sufficiently (i.e. more than 0.7V), it forward biases Q1 and it starts conducting.**

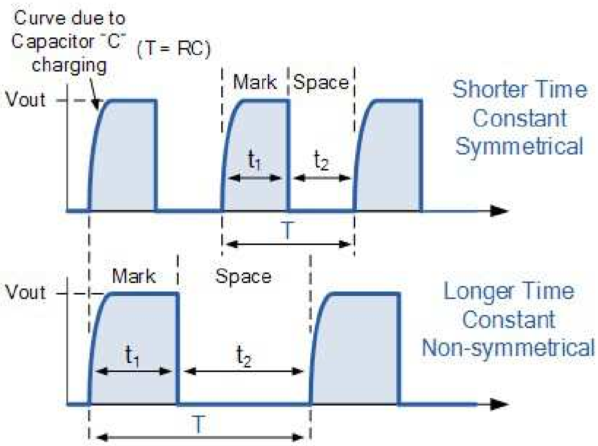
- **In this way, the whole cycle is repeated.**
- **This cyclic phenomenon gives rise to the oscillatory waveform where complementary square signals are generated at the collector terminals of either transistors.**

- **The time in each state depends on RC values.**

Periodic Time, $T = t_1 + t_2$

$$t_1 = 0.69 C_1 R_3$$

$$t_2 = 0.69 C_2 R_2$$



MONOSTABLE MULTIVIBRATORS

MONOSTABLE MULTIVIBRATOR

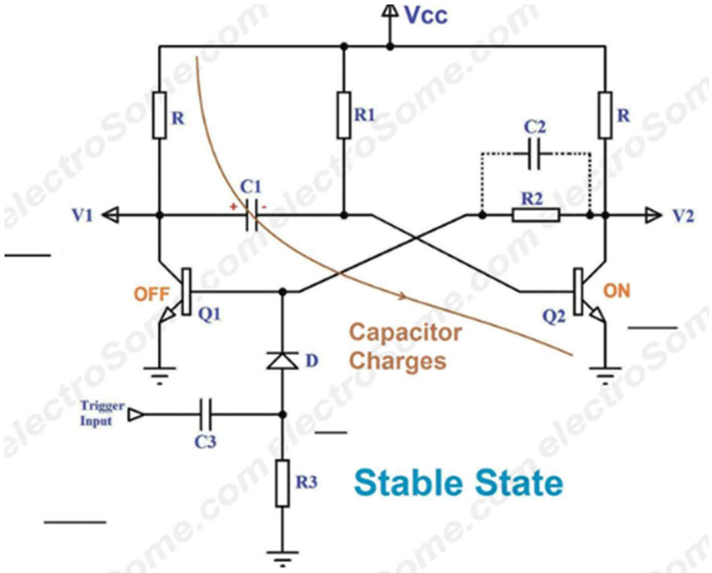
- **Monostable Multivibrator or One-Shot Multivibrator has only one stable state.**
- **By default monostable multivibrator will be in its stable state, but when triggered it will switch to unstable state (quasi-stable state) for a time period determined by the RC time constant in the circuit.**
- **Generally speaking, discrete multivibrators consist of a two transistor cross coupled switching circuit designed so that one or more of its outputs are fed back as an input to the other transistor with a resistor and capacitor (RC) network connected across them to produce the feedback tank circuit.**
- **In this multivibrator, a single narrow input trigger pulse produces single rectangular pulse whose amplitude, pulse width and wave shape depend upon the values of circuit components rather than upon the trigger pulse.**

WORKING

- <u>INITIAL CONDITION</u>

(In the absence of Trigger Pulse)

- When the circuit is switched ON, transistor Q1 will be OFF and Q2 will be ON, since sufficient base current flows to Q2 through R1.
- Capacitor C1 gets charged through R to Vcc during this state.



WHEN TRIGGER PULSE IS APPLIED

- When a trigger pulse is applied to Q1 through C2, the circuit will switch to its opposite unstable state where Q2 is cut-off and Q1 conducts at saturation.
- The chain of circuit actions is as under:

1. If positive trigger pulse is of sufficient amplitude, it will give it a forward bias.

- Hence, Q1 will start conducting.

2. As Q1 conducts, its collector voltage falls.

- It means that potential of V1 falls (negative-going signal).
- This negative-going voltage is fed to Q2 via C1 where it decreases its forward bias.

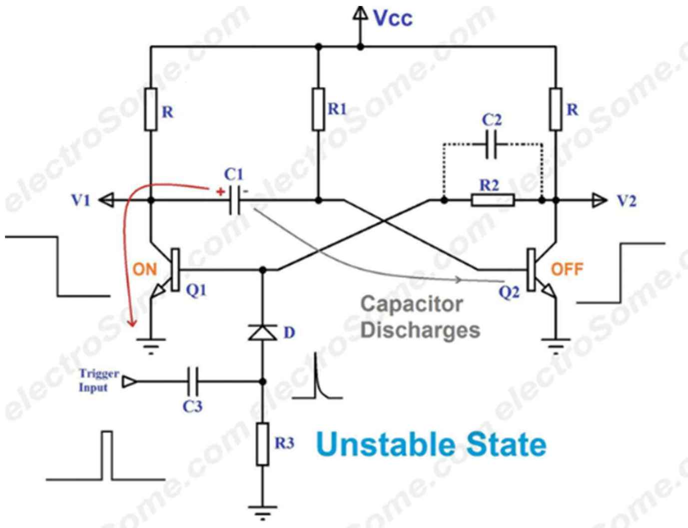
3. As collector current of Q1 starts decreasing, potential of V2 increases (positive-going signal).

- Soon, Q2 comes out of conduction.

4. The positive-going signal at V2 is fed via R2 to the base of Q1 where it increases its forward bias further.

- As Q1 conducts more, potential of point V1 approaches 0 V.

5. This action is cumulative and ends with Q1 conducting at saturation and Q2 cut-off.



RETURN TO INITIAL STABLE STATE

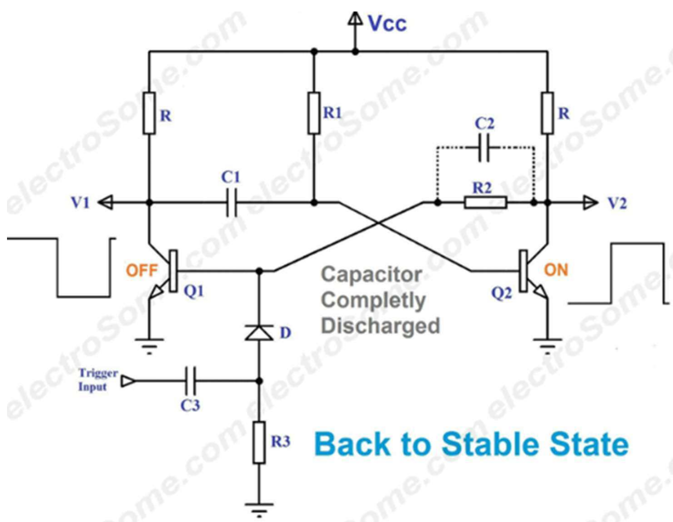
1. As point V1 is at almost 0 V, C1 starts to discharge through saturated Q1 to ground.

2. As C1 discharges, the negative potential at the base of Q2 is decreased.

As C1 discharges further, Q2 is pulled out of cut-off.

3. As Q2 conducts further, a negative-going signal from point V2 via R1 drives Q1 into cut-off.

- Hence, the circuit reverts to its original state with Q2 conducting at saturation and Q1 cut-off.



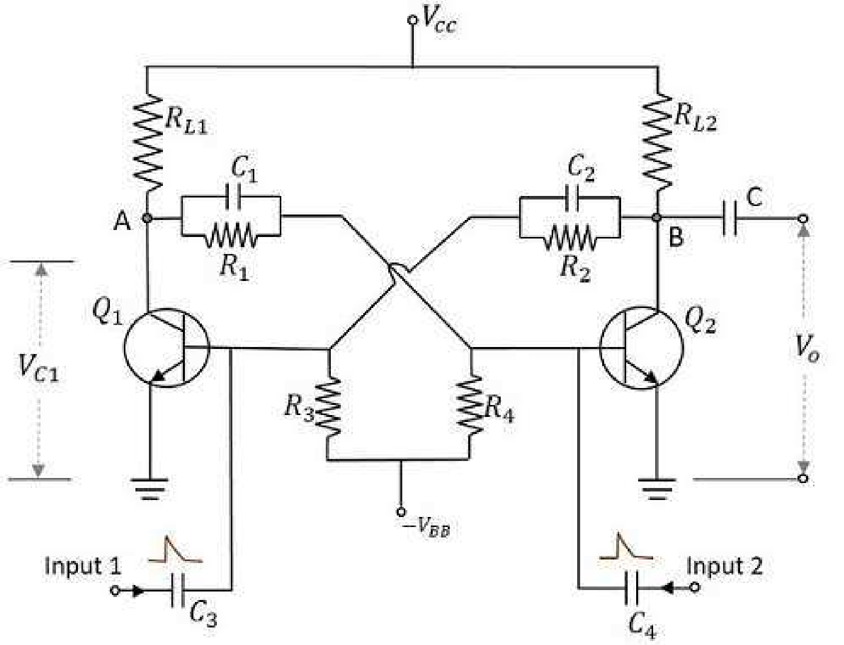
- As shown in Figure, the output is taken from the collector of Q2 though it can also be taken from point V1 of Q1.
- The width of this pulse is determined by the time constant of C1 R1.
- Since this MV produces one output pulse for every input trigger pulse it receives, it is called mono or one-shot multivibrator.
- The width or duration of the pulse is given by

$$T = 0.69\ C1R1$$

- It is also known as the one-shot period.

BISTABLE MULTIVIBRATOR

- A Bistable Multivibrator has two stable states.
- The circuit stays in any one of the two stable states.
- It continues in that state, unless an external trigger pulse is given.
- This Multivibrator is also known as Flip-flop.
- The bistable multivibrator can be switched over from one stable state to the other by the application of an external trigger pulse thus, it requires two external trigger pulses before it returns back to its original state.
- The discrete Bistable Multivibrator is a two state non-regenerative device constructed from two cross-coupled transistors operating as "ON-OFF" transistor switches.
- In each of the two states, one of the transistors is cut-off while the other transistor is in saturation, this means that the bistable circuit is capable of remaining indefinitely in either stable state.

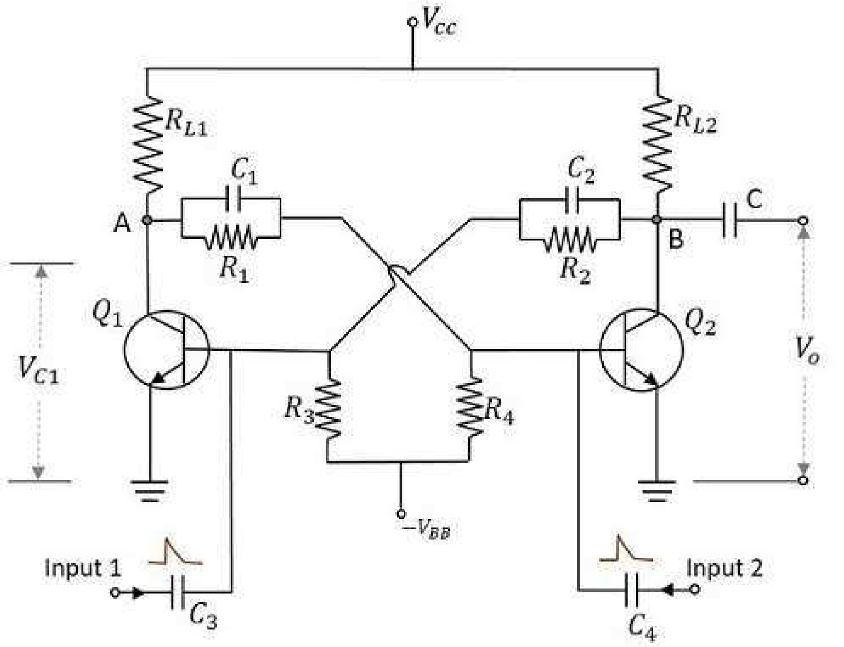


CIRCUIT DESCRIPTION

- **Two similar transistors Q_1 and Q_2 with load resistors R_{L1} and R_{L2} are connected in feedback to one another.**
- **The base resistors R_3 and R_4 are joined to a common source $-V_{BB}$.**
- **The feedback resistors R_1 and R_2 are shunted by capacitors C_1 and C_2 known as Commutating Capacitors.**
- **The transistor Q_1 is given a trigger input at the base through the capacitor C_3 and the transistor Q_2 is given a trigger input at its base through the capacitor C_4.**
- **The capacitors C_1 and C_2 are also known as Speed-up Capacitors, as they reduce the transition time, which means the time taken for the transfer of conduction from one transistor to the other.**

OPERATION

- **When the circuit is switched ON, due to some circuit imbalances as in Astable, one of the transistors, say Q_1 gets switched ON, while the transistor Q_2 gets switched OFF.**
- **This is a stable state of the Bistable Multivibrator.**
- **By applying a negative trigger at the base of transistor Q_1 or by applying a positive trigger pulse at the base of transistor Q_2, this stable state is altered.**
- **So, let us understand this by considering a negative pulse at the base of transistor Q_1.**
- **As a result, the collector voltage increases, which forward biases the transistor Q_2.**
- **The collector current of Q_2 as applied at the base of Q_1, which reverse biases Q_1 and this cumulative action makes the transistor Q_1 OFF and transistor Q_2 ON.**
- **This is another stable state of the Multivibrator.**
- **Now, if this stable state has to be changed again, then either a negative trigger pulse at transistor Q_2 or a positive trigger pulse at transistor Q_1 is applied.**



- **Advantages**
- **The advantages of using a Bistable Multivibrator are as follows −**
- **Stores the previous output unless disturbed.**
- **Circuit design is simple**
- **Disadvantages**
- **The drawbacks of a Bistable Multivibrator are as follows −**
- **Two kinds of trigger pulses are required.**
- **A bit costlier than other Multivibrators.**
- **Applications**
- **Bistable Multivibrators are used in applications such as pulse generation and digital operations like counting and storing of binary information.**