UNIT II OSCILLATORS

Barkhausen criterion for oscillation - Phase shift, Wien bridge - Hartley and Colpitts oscillators - Clapp oscillator - Ring oscillators and crystal oscillators - Oscillator amplitude stabilization.

2.2.Types of Oscillators:

- There are many types of oscillators, but can broadly be classified into two main categories
- Harmonic Oscillators (also known as Linear Oscillators) and
- Relaxation Oscillators.
- In a harmonic oscillator, the energy flow is always from the active components to the passive components and the frequency of oscillations is decided by the feedback path.
- Whereas in a relaxation oscillator, the energy is exchanged between the active and the passive components and the frequency of oscillations is determined by the charging and discharging time-constants involved in the process.
- Further, harmonic oscillators produce low-distorted sine-wave outputs
- while the relaxation oscillators generate non-sinusoidal (saw- tooth, triangular or square) wave-forms.

Sinusoidal or non-sinusoidal.

- An oscillator generating square wave or a pulse train is called multivibrator :

1. Bistable multivibrator (Flip-Flop Circuit).
2. Monostable multivibrator.
3. Astable multivibrator (Free-running).

- Depending upon type of feedback, we have

1. Tuned Circuit (LC) oscillators.
2. RC oscillators, and

3.Crystal oscillators.

The main types of Oscillators include:

1. RC Oscillators
   i. Wien Bridge Oscillator
   ii. RC Phase Shift Oscillator

2. LC Oscillators
   i. Hartley Oscillator
   ii. Colpitts Oscillator
   iii. Clapp Oscillator
3. Crystal Oscillators

2.2.1 Phase shift oscillators

- The RC Oscillator which is also called a Phase Shift Oscillator, produces a sine wave output signal using regenerative feedback from the resistor-capacitor combination.
- This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge, (similar to the LC tank circuit).
- This resistor-capacitor feedback network can be connected as shown above to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360^o.
- By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done using a 3-ganged variable capacitor.

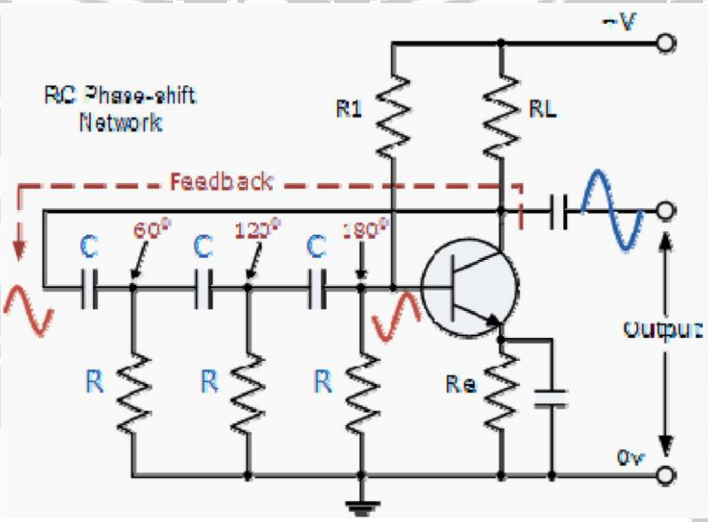

Fig 2.2.1

- If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as:

$$\boxed{f_0 = \frac{1}{2\pi RC\sqrt{6}}}$$

f is the Output Frequency in Hertz R is the Resistance in Ohms

C is the Capacitance in Farads

N is the number of RC stages. (in our example N = 3)

- A phase-lead or phases-lag circuit can provide phase shift between 0° and 90°.
- For total phase shift 180°, we use three identical sections each giving a phase shift of 60°.
- Since the resistor-capacitor combination in the RC Oscillator circuit also acts as an attenuator producing an attenuation of -1/29th (Vo/Vi = β) per stage, the gain of the amplifier must be sufficient to overcome the losses and in our three mesh network above the amplifier gain must be greater than 29.
- The loading effect of the amplifier on the feedback network has an effect on the frequency of oscillations and can cause the oscillator frequency to be up to 25% higher than calculated. Then the feedback network should be driven from a high impedance output source and fed into a low impedance load such as a common emitter transistor amplifier but better still is to use an Operational Amplifier as it satisfies these conditions perfectly.
- *RC phase-shift oscillators* use resistor-capacitor (RC) network (Figure 1) to provide the phase-shift required by the feedback signal.
- They have excellent frequency stability and can yield a pure sine wave for a wide range of loads.

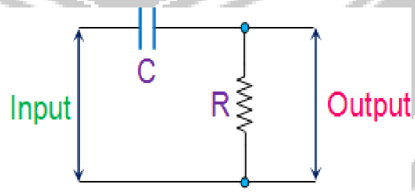

Figure 1 RC Phase-Shift Network

- Ideally a simple RC network is expected to have an output which leads the input by 90°.
- However, in reality, the phase-difference will be less than this as the capacitor used in the circuit cannot be ideal.
- Mathematically the phase angle of the RC network is expressed as

$$\varphi = tan^{-1}\frac{X_C}{R}$$

Where, $X_C = 1/(2\pi fC)$ is the reactance of the capacitor C and R is the resistor. In oscillators, these kind of RC phase-shift networks, each offering a definite phase-shift can be cascaded so as to satisfy the phase-shift condition led by the Barkhausen Criterion.

One such example is the case in which RC phase-shift oscillator is formed by cascading three RC phase-shift networks, each offering a phase-shift of 60°, as shown by Figure 2.

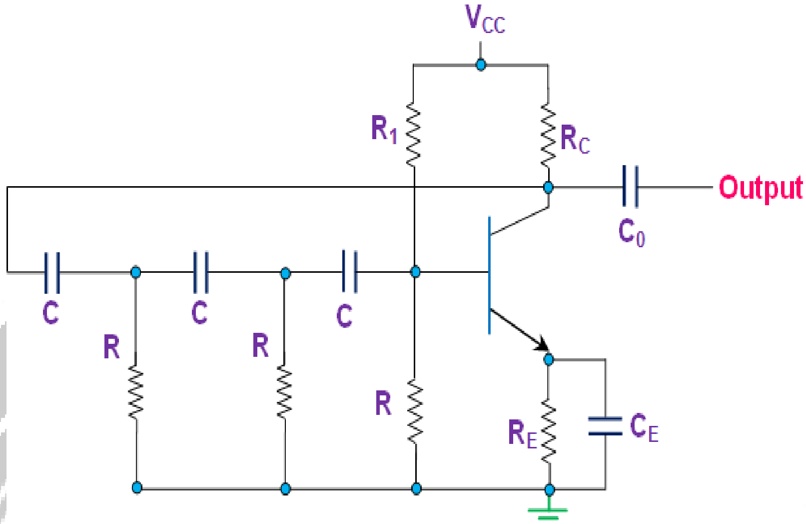

Figure 2 RC Phase-Shift Oscillator Using BJT

- Here the collector resistor Rc limits the collector current of the transistor, resistors R_1 and R (nearest to the transistor) form the voltage divider network while the emitter resistor R_E improves the stability.
- Next, the capacitors C_E and C_o are the emitter by- pass capacitor and the output DC decoupling capacitor, respectively. Further, the circuit also shows three RC networks employed in the feedback path.
- This arrangement causes the output waveform to shift by 180° during its course of travel from output terminal to the base of the transistor.
- Next, this signal will be shifted again by 180° by the transistor in the circuit due to the fact that the phase-difference between the input and the output will be 180° in the case of common emitter configuration.
- This makes the net phase-difference to be 360°, satisfying the phase-difference condition.
- One more way of satisfying the phase-difference condition is to use four RC networks, each offering a phase-shift of 45°.
- Hence it can be concluded that the RC phase-shift oscillators can be designed in many ways as the number of RC networks in them is not fixed.
- However it is to be noted that, although an increase in the number of stages increases the frequency stability of the circuit, it also adversely affects the output frequency of the oscillator due to the loading effect.
- The generalized expression for the frequency of oscillations produced by a RC phase-shift oscillator is given by

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

Where, N is the number of RC stages formed by the resistors R and the capacitors C.

- Further, as is the case for most type of oscillators, even the RC phase-shift oscillators can be designed using an OpAmp as its part of the amplifier section (Figure 3). Nevertheless, the mode of working remains the same while it is to be noted that, here, the required phase-shift of 360º is offered collectively by the RC phase-shift networks and the Op-Amp working in inverted configuration.

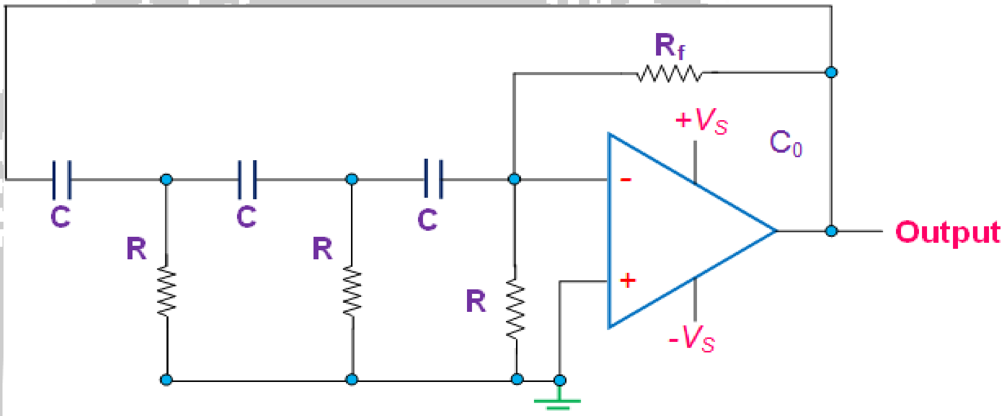

Figure 3 RC Phase-Shift Oscillator Using an Op-Amp

Further, it is to be noted that the frequency of the RC phase-shift oscillators can be varied by changing either the resistors or the capacitors. However, in general, the resistors are kept constant while the capacitors are gang-tuned. Next, by comparing the RC phase-shift oscillators with LC oscillators, one can note that, the former uses more number of circuit components than the latter one. Thus, the output frequency produced from the RC oscillators can deviate much from the calculated value rather than in the case of LC oscillators. Nevertheless, they are used as local oscillators for synchronous receivers, musical instruments and as low and/or audio-frequency generators.

2.2.3Wien bridge oscillators

- A Wien-Bridge Oscillator is a type of phase-shift oscillator which is based upon a Wien-Bridge network comprising of four arms connected in a bridge fashion.
- Here two arms are purely resistive while the other two arms are a combination of resistors and capacitors.
- In particular, one arm has resistor and capacitor connected in series (R_1 and C_1) while the other has them in parallel (R_2 and C_2). This indicates that these two arms of

the network behave identical to that of high pass filter or low pass filter, mimicking the behavior of the circuit shown by Figure.

- In this circuit, at high frequencies, the reactance of the capacitors C_1 and C_2 will be much less due to which the voltage V_0 will become zero as R_2 will be shorted. Next, at low frequencies, the reactance of the capacitors C_1 and C_2 will become very high.
- However even in this case, the output voltage V_0 will remain at zero only, as the capacitor C_1 would be acting as an open circuit.
- This kind of behavior exhibited by the Wien-Bridge network makes it a lead-lag circuit in the case of low and high frequencies, respectively.

2.2.4 Wien Bridge Oscillator Frequency Calculation:

- Nevertheless, amidst these two high and low frequencies, there exists a particular frequency at which the values of the resistance and the capacitive reactance will become equal to each other, producing the maximum output voltage. This frequency is referred to as resonant frequency. The resonant frequency for a Wein Bridge Oscillator is calculated using the following formula:

$$f_r = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$$if\ R_1 = R_2 = R\ and\ C_1 = C_2 = C$$

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

- Further, at this frequency, the phase-shift between the input and the output will become zero and the magnitude of the output voltage will become equal to one-third of the input value. In addition, it is seen that the Wien-Bridge will be balanced only at this particular frequency.
- In the case of Wien-Bridge oscillator, the Wien-Bridge network of Figure 1 will be used in the feedback path as shown in Figure 2. The circuit diagram for a Wein Oscillator using a BJT (Bipolar Junction Transistor) is shown below:

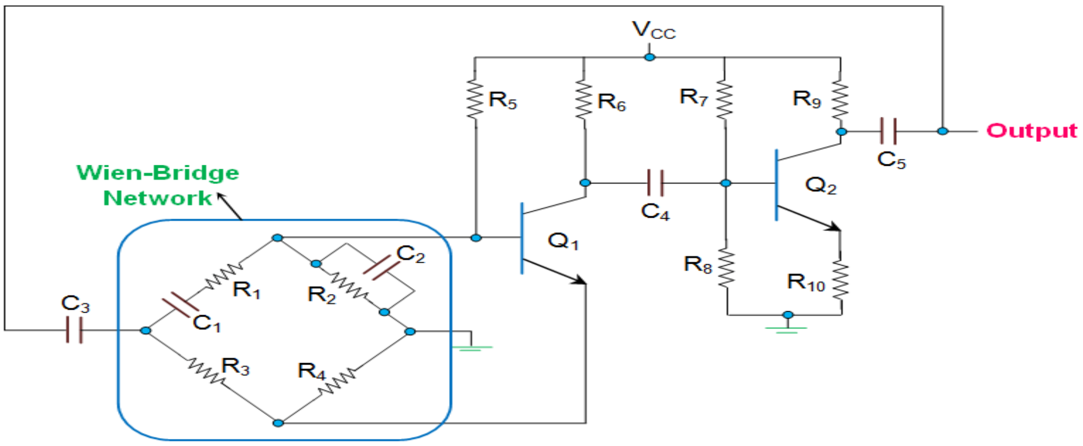

Figure 2 Wien-Bridge Oscillator Using BJT

- In these oscillators, the amplifier section will comprise of two-stage amplifier formed by the transistors, Q_1 and Q_2, wherein the output of Q_2 is back-fed as an input to Q_1 via Wien-Bridge network (shown within the blue enclosure in the figure). Here, the noise inherent in the circuit will cause a change in the base current of Q_1 which will appear at its collector point after being amplified with a phase-shift of 180^o.
- This is fed as an input to Q_2 via C_4 and gets further amplified and appears with an additional phase-shift of 180^o. This makes the net phase-difference of the signal fed back to the Wien-Bridge network to be 360^o, satisfying phase-shift criterion to obtain sustained oscillations.
- However, this condition will be satisfied only in the case of resonant frequency, due to which the Wien-Bridge oscillators will be highly selective in terms of frequency, leading to a frequency-stabilized design.
- Wien-bridge oscillators can even be designed using Op-Amps as a part of their amplifier section, as shown by Figure 3. However it is to be noted that, here, the Op-Amp is required to act as a non-inverting amplifier as the Wien-Bridge network offers zero phase-shift. Further, from the circuit, it is evident that the output voltage is fed back to both inverting and non- inverting input terminals.
- At resonant frequency, the voltages applied to the inverting and non- inverting terminals will be equal and in-phase with each other. However, even here, the voltage gain of the amplifier needs to be greater than 3 to start oscillations and equal to 3 to sustain them. In general, these kind of Op-Amp-based Wien Bridge Oscillators cannot operate above 1 MHz due to the limitations imposed on them by their open-loop gain.

$$Z_1 = R_1 + 1/ jwC_1 = (1 + jwR_1C_1) / jwC_1$$

$$Z_2 = R_2 \parallel 1/ jwC_2 = R_2 / (1 + jwR_2C_2)$$

- Replacing jw = s

- $Z_1 = (1 + s R_1C_1) / sC_1$
- $Z_2 = R_2 / (1 + sR_2C_2)$

- $I = V_{in} / (Z_1 + Z_2)$
- $V_f = I Z_2$
- $V_f = V_{in} Z_2 / (Z_1 + Z_2)$

- Sub Z_1 & Z_2 Value ; replace $s = jw$, $s^2 = -w^2$

$$\beta = \frac{w^2 C_1 R_2 (R_1C_1 + R_2C_2 + C_1R_2) + jwC_1R_2(1 - w^2R_1R_2C_1C_2)}{(1 - w^2R_1R_2C_1C_2)^2 + w^2 (R_1C_1 + R_2C_2 + C_1R_2)^2}$$

- To have zero phase shift of the feedback n/w imaginary part must be zero

$$wC_1R_2 (1 - w^2R_1R_2C_1C_2) = 0$$

$$1 - w^2R_1R_2C_1C_2 = 0$$

$$W^2 = 1 / R_1R_2C_1C_2$$

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

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

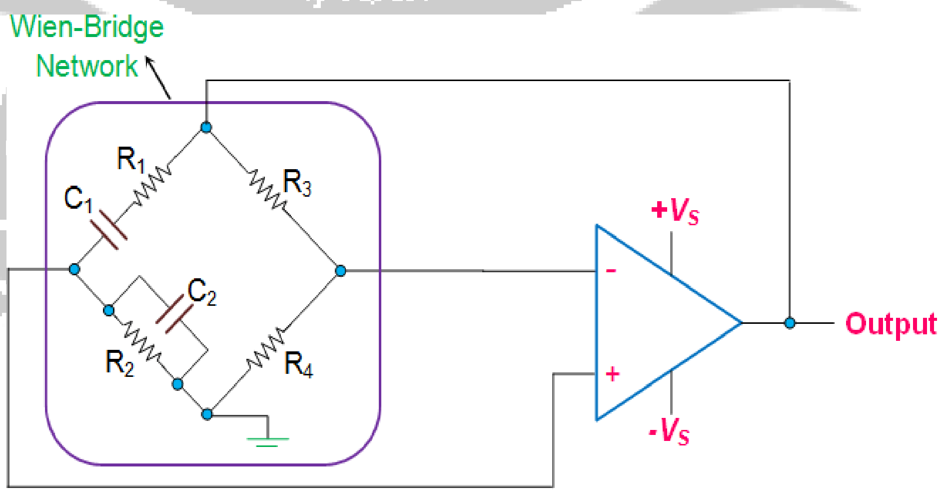

Figure 3 Wien-Bridge Oscillator Using an Op-Amp

- Wien-Bridge networks are low frequency oscillators which are used to generate audio and sub-audio frequencies ranging between 20 Hz to 20 KHz. Further, they provide stabilized, low distorted sinusoidal output over a wide range of frequency which can be selected using decade resistance boxes.

- In addition, the oscillation frequency in this kind of circuit can be varied quite easily as it just needs variation of the capacitors C_1 and C_2.
- However these oscillators require large number of circuit components and can be operated up to a certain maximum frequency only.