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SCHOOL OF COMPUTING

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

DEPARTMENT OF INFORMATION TECHNOLOGTY

UNIT - V
Electrical and Electronics Engineering – SEEA1103

UNIT-5
RECTIFIERS, AMPLIFIERS AND OSCILLATORS

RECIFIERS

A rectifier is nothing but a simple diode or group of diodes which converts the Alternating Current (AC) into Direct Current (DC).

We know that a diode allows electric current in one direction and blocks electric current in another direction. We are using this principle to construct various types of rectifiers. Rectifiers are classified into different types based on the number of diodes used in the circuit or arrangement of diodes in the circuit.

The basic types of rectifiers are:

- Half wave rectifier
- Full wave rectifier.

Half wave rectifier definition

A half wave rectifier is a type of rectifier which converts the positive half cycle (positive current) of the input signal into pulsating DC (Direct Current) output signal.

or

A half wave rectifier is a type of rectifier which allows only half cycle (either positive half cycle or negative half cycle) of the input AC signal while the half cycle is blocked.

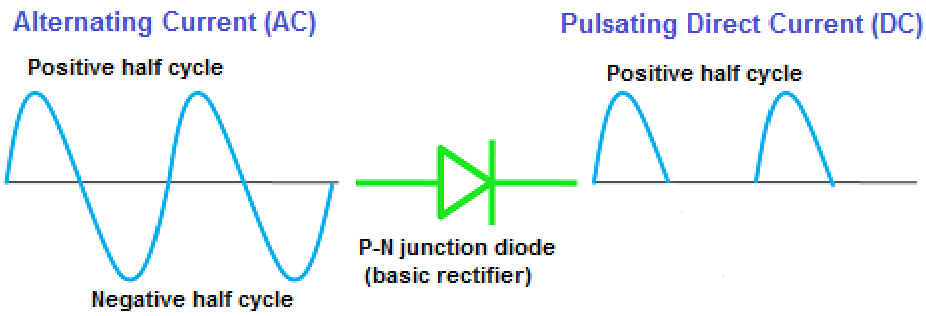


Fig 5.1: Waveforms of AC and DC

For example, if the positive half cycle is allowed then the negative half cycle is blocked. Similarly, if the negative half cycle is allowed then the positive half cycle is blocked. However, a half wave rectifier will not allow both positive and negative half cycles at the same time. Therefore, the half cycle (either positive or negative) of the input signal is wasted.

HALF WAVE RECTIFIER OPERATION

The half wave rectifier is the simplest form of the rectifier. We use only a single diode to construct the half wave rectifier. The half wave rectifier is made up of an AC source, transformer (step-down), diode, and resistor (load). The diode is placed between the transformer and resistor (load).

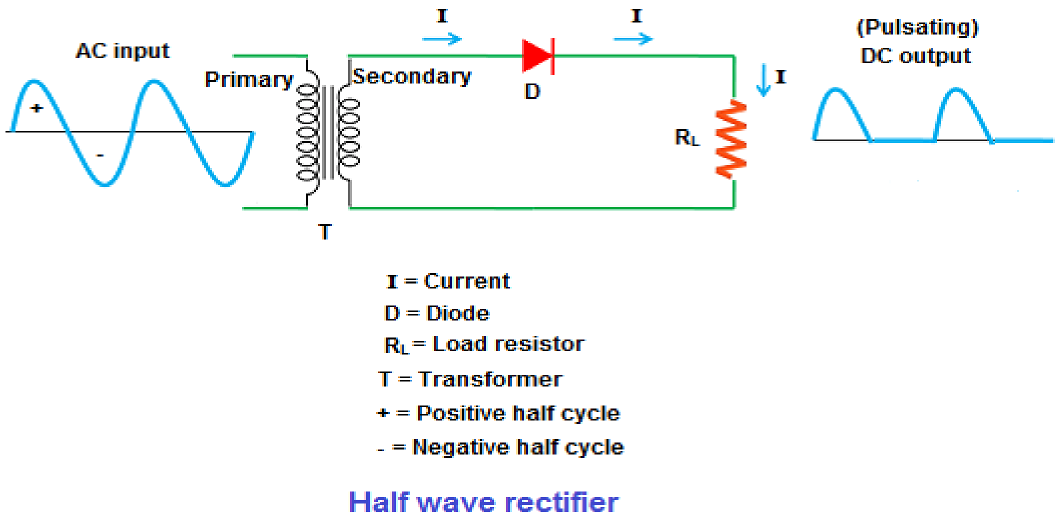


Fig 5.2: Half wave Rectifier

AC source

The AC source supplies Alternating Current to the circuit. The alternating current is often represented by a sinusoidal waveform.

Transformer

Transformer is a device which reduces or increases the AC voltage. The step-down transformer reduces the AC voltage from high to low whereas the step-up transformer increases the AC voltage from low to high. In half wave rectifier, we generally use a step-down transformer because the voltage needed for the diode is very small. Applying a large AC voltage without using transformer will permanently destroy the diode. So we use step-down transformer in half wave rectifier. However, in some cases, we use a step-up transformer.In the step-down transformer, the primary winding has more turns than the secondary winding. So the step-down transformer reduces the voltage from primary winding to secondary winding.

Diode

A diode is a two terminal device that allows electric current in one direction and blocks electric current in another direction.

Resistor

A resistor is an electronic component that restricts the current flow to a certain level.

Half wave rectifier operation

Positive half wave rectifier

When high AC voltage (60 Hz) is applied, the step-down transformer reduces this high voltage into low voltage. Thus, a low voltage is produced at the secondary winding of the transformer. The low voltage produced at the secondary winding of the transformer is called secondary voltage (V_S). The AC voltage or AC signal applied to the transformer is nothing but an input AC signal or input AC voltage.

The low AC voltage produced by the step-down transformer is directly applied to the diode.

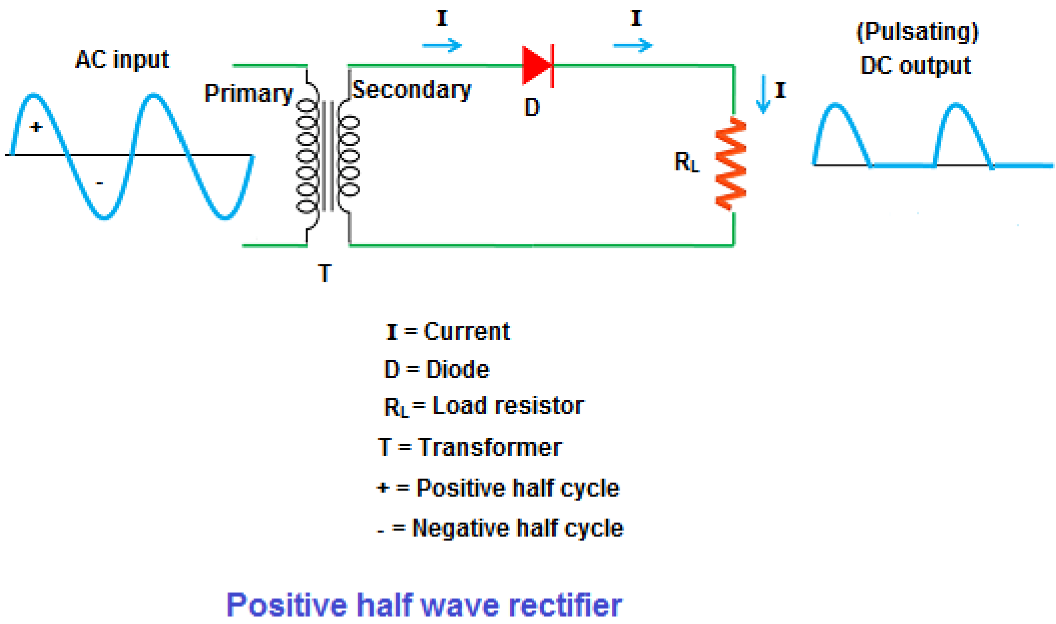


Fig 5.3: Positive Half wave Rectifier

When low AC voltage is applied to the diode (D), during the positive half cycle of the signal, the diode is forward biased and allows electric current whereas, during the negative half cycle, the diode is reverse biased and blocks electric current. In simple words, the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal.

The positive half-cycle of the input AC signal or AC voltage applied to the diode is analogous to the forward DC voltage applied to the p-n junction diode similarly the negative half-cycle of the input AC signal applied to the diode is analogous to the reverse DC voltage applied to the p-n junction diode.

We know that diode allows electric current when it is forward biased and blocks electric current when it is reverse biased. Similarly, in an AC circuit, the diode allows electric current during the positive half cycle (forward biased) and blocks electric current during the negative half cycle (reverse biased).

The positive half wave rectifier does not completely block the negative half cycles. It allows a small portion of negative half cycles or small negative current. This current is produced by the minority carriers in the diode.The current produced by the minority carriers is very small. So it is neglected. We can't visually see the small portion of negative half cycles at the output.

In an ideal diode, the negative half cycles or negative current is zero.The resistor placed at the output consumes the DC current generated by the diode. Hence, the resistor is also known as an electrical load. The output DC voltage or DC current is measured across the load resistor RL.

The electrical load is nothing but an electrical component of a circuit that consumes electric current. In half waverectifier, the resistor consumes the DC current generated by the diode. So the resistor in half wave rectifier is known as a load. Sometimes, the load is also refers to the power consumed by the circuit.

The load resistors are used in half wave rectifiers to restrict or block the unusual excess DC current produced by the diode.

Thus, the half wave rectifier allows positive half cycles and blocks negative half cycles. The half wave rectifier which allows positive half cycles and blocks negative half cycles is called a positive half wave rectifier. The output DC current or DC signal produced by a positive half wave rectifier is a series of positive half cycles or positive sinusoidal pulses.

Negative half wave rectifier

The construction and working of negative half wave rectifier is almost similar to the positive half wave rectifier. The only thing we change here is the direction of a diode.When AC voltage is applied, the step-down transformer reduces the high voltage to low voltage. This low voltage is applied to the diode.

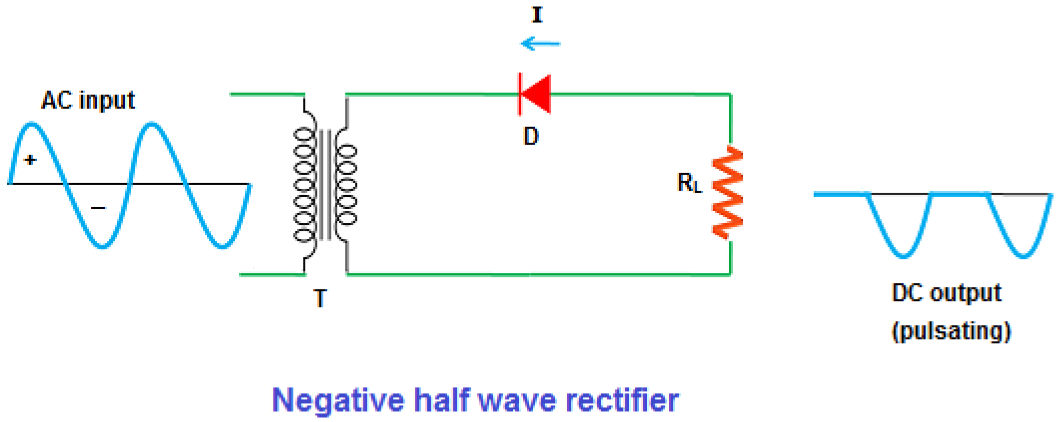


Fig 5.4: Negative Half wave Rectifier

Unlike the positive half wave rectifier, the negative half wave rectifier allows electric current during the negative half-cycle of input AC signal and blocks electric current during the positive half-cycle of the input AC signal.

During the negative half cycle, the diode is forward biased and during the positive half cycle the diode is reverse biased, so the negative half wave rectifier allows electric current only during the negative half cycle.

Thus, the negative half wave rectifier allows negative half cycles and blocks positive half cycles.

The negative half wave rectifier does not completely block the positive half cycles. It allows a small portion of positive half cycles or small positive current. This current is produced by the minority carriers in the diode.

The current produced by the minority carriers is very small. So it is neglected. We can't visually see this small positive half cycles at the output. In an ideal diode, the positive half cycle or positive current is zero.

The DC current or DC voltage produced by the negative half wave rectifier is measured across the load resistor RL. The output DC current or DC signal produced by a negative half wave rectifier is a series of negative half cycles or negative sinusoidal pulses.

Thus, a negative half wave rectifier produces a series of negative sinusoidal pulses.

In a perfect or ideal diode, the positive half cycle or negative half cycle at the output is exactly same as the input positive half cycle or negative half cycle. However, in practice, the positive half cycle or negative half cycle at the output is slightly different from the input positive half cycle or negative half cycle. But this difference is negligible. So we can't see the difference with our eyes.

Thus, the half wave rectifier produces a series of positive sinusoidal pulses or negative sinusoidal pulses. This series of positive pulses or negative pulses is not a pure direct current. It is a pulsating direct current.

The pulsating direct current changes its value over a short period of time. But our aim is to produce a direct current which does not change its value over a short period of time. Therefore, the pulsating direct current is not much useful. Half wave rectifier with capacitor filter

A filter converts the pulsating direct current into pure direct current. In half wave rectifiers, a capacitor or inductor is used as a filter to convert the pulsating DC to pure DC. The output voltage produced by a half wave rectifier is not constant; it varies with respect to time. In practical applications, a constant DC supply voltage is needed. In order to produce a constant DC voltage, we need to suppress the ripples of a DC voltage. This can be achieved by using either a capacitor filter or inductor filter at the output side. In the below circuit, we are using the capacitor filter. The capacitor placed at the output side smoothen the pulsating DC to pure DC.

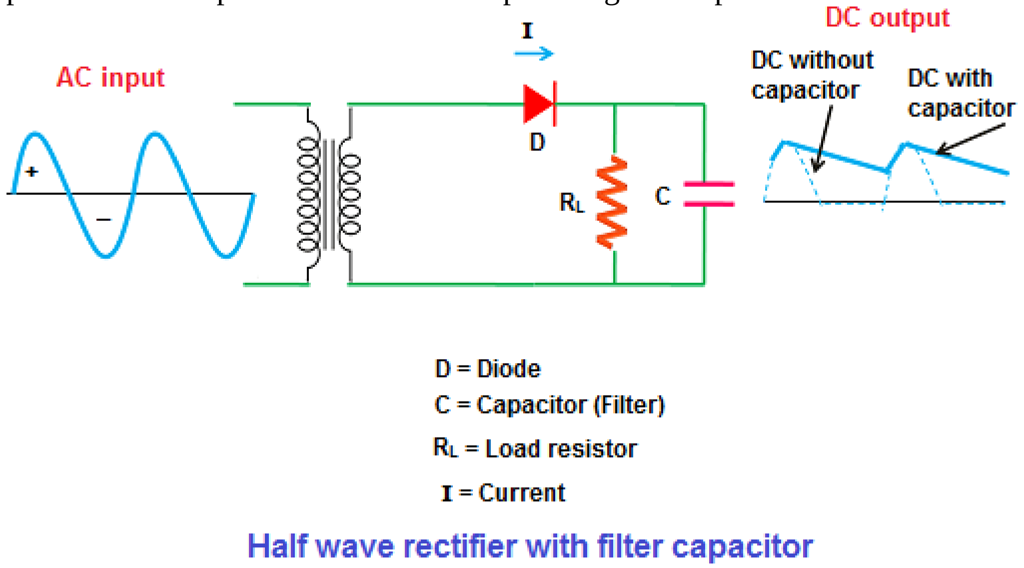


Fig 5.5: Half wave Rectifier with filter Capacitor

Characteristics of half wave Rectifier

Ripple factor

The direct current (DC) produced by a half wave rectifier is not a pure DC but a pulsating DC. In the output pulsating DC signal, we find ripples. These ripples in the output DC signal can be reduced by using filters such capacitors and inductors.

In order to measure how much ripples are there in the output DC signal we use a factor known as ripple factor. The ripple factor is denoted by γ.

The ripple factor tells us the amount of ripples present in the output DC signal.

A large ripple factor indicates a high pulsating DC signal while a low ripple factor indicates a low pulsating DC signal. If the ripple factor is very low then it indicates that the output DC current is closer to the pure DC current. In simple words, the lower the ripple factor the smoother the output DC signal.

Ripple factor can be mathematically defined as the ratio of rms value of AC component of the output voltage to the DC component of the output voltage.

Ripples factor = rms value of AC component of the output voltage / DC component of the output voltage Where, rms = root mean square

or

The ripple factor is also simply defined as the ratio of ripple voltage to the DC voltage Ripple factor = Ratio of ripple voltage / DC voltage

The ripple factor should be kept as minimum as possible to construct a good rectifier. The ripple factor is given as

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

Finally, we get

$\gamma = 1.21$

The unwanted ripple present in the output along with the DC voltage is 121% of the DC magnitude. This indicates that the half wave rectifier is not an efficient AC to DC converter. The high ripples in the half wave rectifier can be reduced by using filters.

DC current The DC current is given by,

$$I_{DC} = \frac{I_{max}}{\pi}$$

Where,

Imax = maximum DC load current

Output DC voltage (VDC)

The output DC voltage (VDC) is the voltage appeared at the load resistor (RL). This voltage is obtained by multiplying the output DC current with load resistance RL.

VDC = IDC RL

$$V_{DC} = \frac{V_{Smax}}{\pi}$$

Where, VSmax = Maximum secondary voltage Peak inverse voltage (PIV)

Peak inverse voltage is the maximum reverse bias voltage up to which a diode can withstand. If the applied voltage is greater than the peak inverse voltage, the diode will be destroyed.

During the positive half cycle, the diode is forward biased and allows electric current. This current is dropped at the resistor load (RL). However, during the negative half cycle, the diode is reverse biased and does not allows electric current, so the input AC current or AC voltage is dropped at the diode.

The maximum voltage dropped at the diode is nothing but an input voltage. Therefore, peak inverse voltage (PIV) of diode = VSmax

Rectifier efficiency

Rectifier efficiency is defined as the ratio of output DC power to the input AC power. The rectifier efficiency of a half wave rectifier is 40.6%

Root mean square (RMS) value of load current IRMS

The root mean square (RMS) value of load current in a half wave rectifier is

$$I_{RMS} = \frac{I_m}{2}$$

Root mean square (RMS) value of output load voltage VRMS

The root mean square (RMS) value of output load voltage in a half wave rectifier is

$$V_{RMS} = I_{RMS}\, R_L = \frac{I_m}{2}\, R_L$$

Form factor

Form factor is defined as the ratio of RMS value to the DC value It can be mathematically written as

F.F = RMS value / DC value

The form factor of a half wave rectifier is

F.F = 1.57

Full wave rectifier

The process of converting the AC current into DC current is called rectification. Rectification can be achieved by using a single diode or group of diodes. These diodes which convert the AC current into DC current are called rectifiers.

Rectifiers are generally classified into two types: half wave rectifier and full wave rectifier.

A half wave rectifier uses only a single diode to convert AC to DC. So it is very easy to construct the half wave rectifier. However, a single diode in half wave rectifier only allows either a positive half cycle or a negative half cycle of the input AC signal and the remaining half cycle of the input AC signal is blocked. As a result, a large amount of power is wasted. Furthermore, the half wave rectifiers are not suitable in the applications which need a steady and smooth DC voltage. So the half wave rectifiers are not efficient AC to DC converters.

We can easily overcome this drawback by using another type of rectifier known as a full wave rectifier. The full wave rectifier has some basic advantages over the half wave rectifier. The average DC output voltage produced by the full wave rectifier is higher than the half wave rectifier. Furthermore, the DC output signal of the full wave rectifier has fewer ripples than the half wave rectifier. As a result, we get a smoother output DC voltage.

Full wave rectifier definition

A full wave rectifier is a type of rectifier which converts both half cycles of the AC signal into pulsating DC signal.

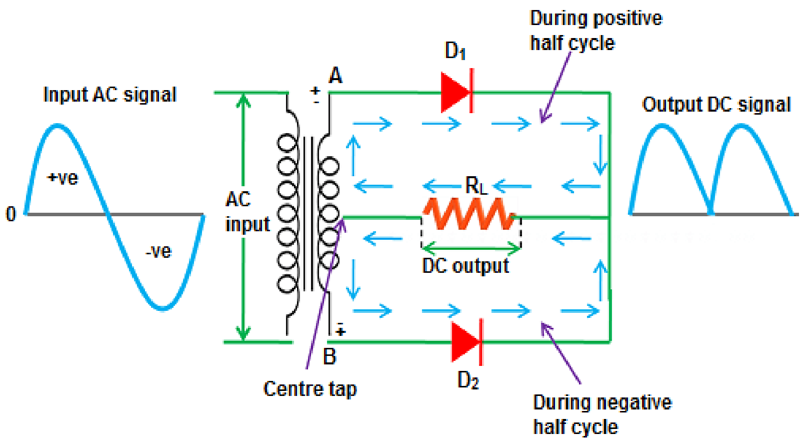


Fig 5.6: Full wave Rectifier

As shown in the above figure, the full wave rectifier converts both positive and negative half cycles of the input AC signal into output pulsating DC signal.

The full wave rectifier is further classified into two types:

- Centre tapped full wave rectifier
- Full wave bridge rectifier.

In this tutorial, centre tapped full wave rectifier is explained. Before going to the working of a centre tapped full wave rectifier, let's first take a look at the centre tapped transformer. Because the centre tapped transformer plays a key role in the centre tapped full wave rectifier.

Centre tapped transformer

When an additional wire is connected across the exact middle of the secondary winding of a

The wire is adjusted in such a way that it falls in the exact middle point of the secondary winding. So the wire is exactly at zero volts of the AC signal.

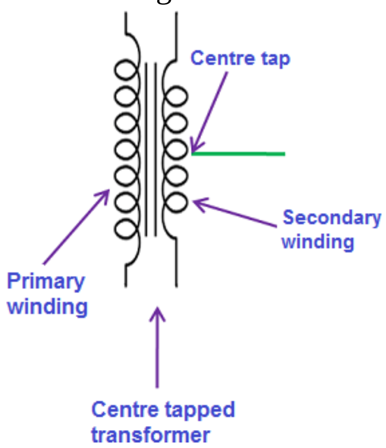


Fig 5.7**: Centre tapped transformer**

This wire is known as the centre tap. The centre tapped transformer works almost similar to a normal transformer. Like a normal transformer, the centre tapped transformer also increases or reduces the AC voltage. However, a centre tapped transformer has another important feature. That is the secondary winding of the centre tapped transformer divides the input AC current or AC signal (V_P) into two parts.

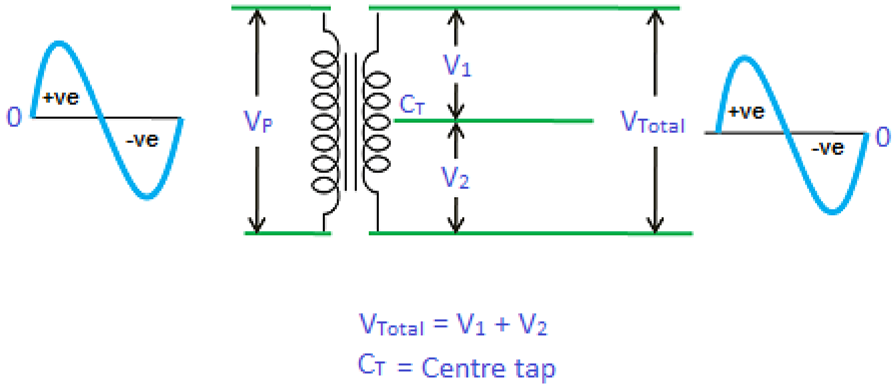


Fig 5.8: Centre tapped transformer with Input supply

The upper part of the secondary winding produces a positive voltage V1 and the lower part of the secondary winding produces a negative voltage V2. When we combine these two voltages at output load, we get a complete AC signal.

I.e. VTotal = V1 + V2

The voltages V1 and V2 are equal in magnitude but opposite in direction. That is the voltages (V1 and V2) produced by the upper part and lower part of the secondary winding are 180 degrees out of phase with each other. However, by using a full wave rectifier with centre tapped transformer, we can produce the voltages that are in phase with each other. In simple words, by using a full wave rectifier with centre tapped transformer, we can produce a current that flows only in single direction.

What is centre tapped full wave rectifier

A center tapped full wave rectifier is a type of rectifier which uses a centre tapped transformer and two diodes to convert the complete AC signal into DC signal.

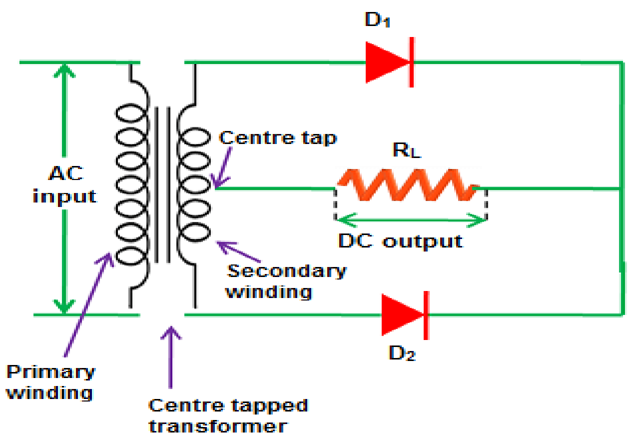


Fig 5.9: Centre tapped full wave rectifier

The centre tapped full wave rectifier is made up of an AC source, a center tapped transformer, two diodes, and a load resistor.

The AC source is connected to the primary winding of the centre tapped transformer. A centre tap (additional wire) connected at the exact middle of the the secondary winding divides the input voltage into two parts. The upper part of the secondary winding is connected to the diode D_1 and the lower part of the secondary winding is connected to the diode D_2. Both diode D_1 and diode D_2 are connected to a common load R_L with the help of a centre tap transformer. The centre tap is generally considered as the ground point or the zero voltage reference point.

How centre tapped full wave rectifier works

The centre tapped full wave rectifier uses a centre tapped transformer to convert the input AC voltage into output DC voltage. When input AC voltage is applied, the secondary winding of the centre tapped transformer divides this input AC voltage into two parts: positive and negative.

During the positive half cycle of the input AC signal, terminal A become positive, terminal B become negative and centre tap is grounded (zero volts). The positive terminal A is connected to the p-side of the diode D_1 and the negative terminal B is connected to the n-side of the diode D_1. So the diode D_1 is forward biased during the positive half cycle and allows electric current through it.

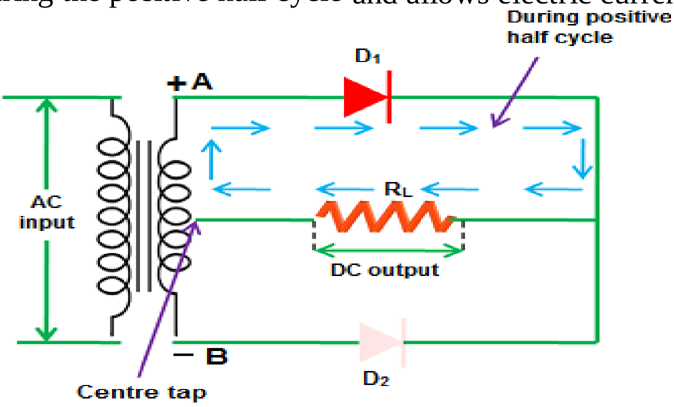


Fig 5.10**: Centre tapped full wave rectifier during Positive half cycle**

On the other hand, the negative terminal B is connected to the p-side of the diode D_2 and the positive terminal A is connected to the n-side of the diode D_2. So the diode D_2 is reversed biased during the positive half cycle and does not allow electric current through it.

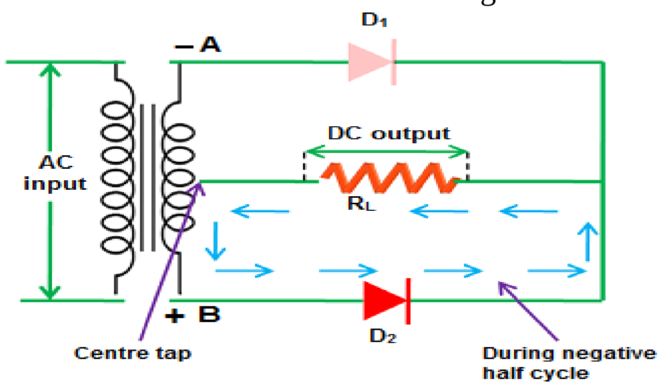


Fig 5.11**: Centre tapped full wave rectifier during Negative half cycle**

The diode D_1 supplies DC current to the load R_L. The DC current produced at the load R_L will return to the secondary winding through a centre tap. During the positive half cycle, current flows only in the upper part of the circuit while the lower part of the circuit carry no current to the load because the diode D_2 is reverse biased. Thus, during the positive half cycle of the input AC signal, only diode D_1 allows electric current while diode D_2 does not allow electric current. During the negative half cycle of the input AC signal, terminal A become negative, terminal B become positive and centre tap is grounded (zero volts). The negative terminal A is connected to the p-side of the diode D_1 and the positive terminal B is connected to the n-side of the diode D_1. So the diode D_1 is reverse biased during the negative half cycle and does not allow electric current through it.On the other hand, the positive terminal B is connected to the p-side of the diode D_2 and the negative terminal A is connected to the n-side of the diode D_2. So the diode D_2 is forward biased during the negative half cycle and allows electric current through it. The diode D_2 supplies DC current to the load R_L.

The DC current produced at the load R_L will return to the secondary winding through a centre tap.

During the negative half cycle, current flows only in the lower part of the circuit while the upper part of the circuit carry no current to the load because the diode D_1 is reverse biased. Thus, during the negative half cycle of the input AC signal, only diode D_2 allows electric current while diode D_1 does not allow electric current. Thus, the diode D_1 allows electric current during the positive half cycle and diode D_2 allows electric current during the negative half cycle of the input AC signal. As a result, both half cycles (positive and negative) of the input AC signal are allowed. So the output DC voltage is almost equal to the input AC voltage.

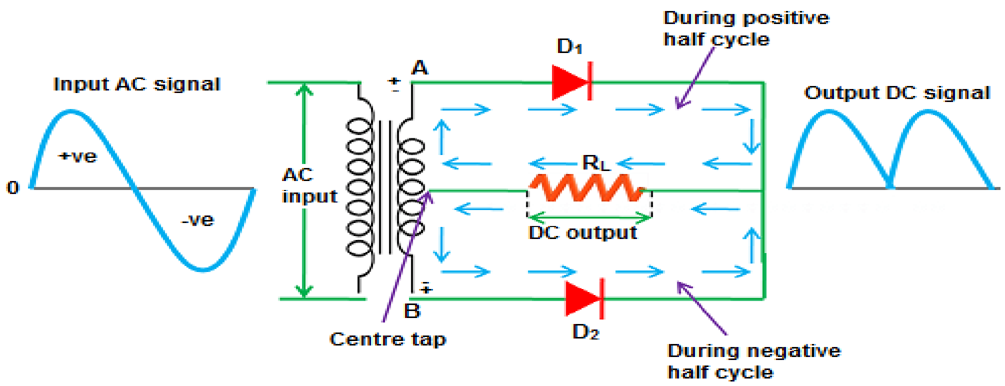


Fig 5.12**: Centre tapped full wave rectifier during Positive and Negative half cycle**

A small voltage is wasted at the diode D_1 and diode D_2 to make them conduct. However, this voltage is very small as compared to the voltage appeared at the output. So this voltage is neglected. The diodes D_1 and D_2 are commonly connected to the load R_L. So the load current is the sums of individual diode currents. We know that a diode allows electric current in only one direction. From the above diagram, we can see that both the diodes D_1 and D_2 are allowing current in the same direction.

We know that a current that flows in only single direction is called a direct current. So the resultant current at the output (load) is a direct current (DC). However, the direct current appeared at the output is not a pure direct current but a pulsating direct current. The value of the pulsating direct current changes with respect to time. This is due to the ripples in the output signal. These ripples can be reduced by using filters such as capacitor and inductor. The average output DC voltage across the load resistor is double that of the single half wave rectifier circuit.

Output waveforms of full wave rectifier

The output waveforms of the full wave rectifier is shown in the below figure.

The first waveform represents an input AC signal. The second waveform and third waveform represents the DC signals or DC current produced by diode D_1 and diode D_2. The last waveform represents the total output DC current produced by diodes D_1 and D_2. From the above waveforms, we can conclude that the output current produced at the load resistor is not a pure DC but a pulsating DC.

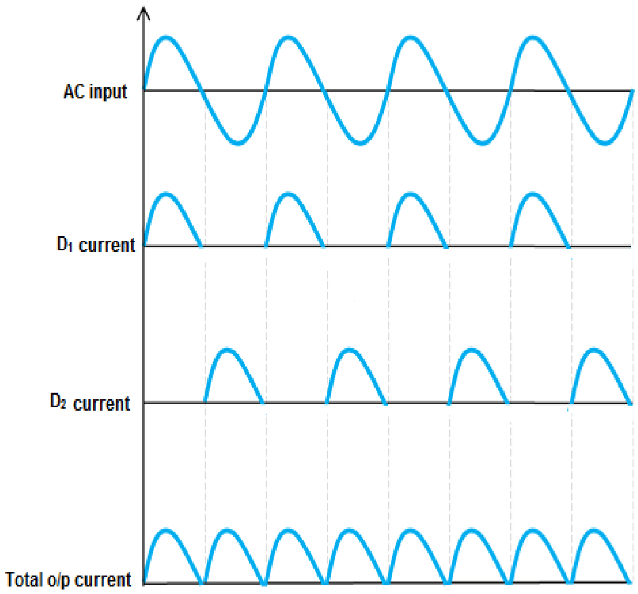


Fig 5.13**: Output waveforms of full wave rectifier**

Characteristics of full wave rectifier
Ripple factor

The ripple factor is used to measure the amount of ripples present in the output DC signal. A high ripple factor indicates a high pulsating DC signal while a low ripple factor indicates a low pulsating DC signal.
Ripple factor is defined as the ratio of ripple voltage to the pure
DC voltage The ripple factor is given by

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

Finally, we get

$$\gamma = \mathbf{0.48}$$

Rectifier efficiency

Rectifier efficiency indicates how efficiently the rectifier converts AC into DC. A high percentage of rectifier efficiency indicates a good rectifier while a low percentage of rectifier efficiency indicates an inefficient rectifier.
Rectifier efficiency is defined as the ratio of DC output power to the AC input power.
It can be mathematically written as

$$\eta = \text{output } P_{DC} \, / \, \text{input } P_{AC}$$

The rectifier efficiency of a full wave rectifier is 81.2%.

The rectifier efficiency of a full wave rectifier is twice that of the half wave rectifier. So the full wave rectifier is more efficient than a half wave rectifier

Peak inverse voltage (PIV)

Peak inverse voltage or peak reverse voltage is the maximum voltage a diode can withstand in the reverse bias condition. If the applied voltage is greater than the peak inverse voltage, the diode will be permanently destroyed.
The peak inverse voltage (PIV) = $2V_{smax}$

DC output current

At the output load resistor R_L, both the diode D_1 and diode D_2 currents flow in the same direction. So the output current is the sum of D_1 and D_2 currents. The current produced by D_1 is I_{max} / π and the current produced by D_2 is I_{max} / π.So the output current

$$I_{DC} = 2I_{max} / \pi$$

Where,

I_{max} = maximum DC load current

DC output voltage

The DC output voltage appeared at the load resistor R_L is given as

$$V_{DC} = 2V_{max} / \pi$$

Where,

V_{max} = maximum secondary voltage

Root mean square (RMS) value of load current I_{RMS}

The root mean square (RMS) value of load current in a full wave rectifier is

$$I_{RMS} = \frac{I_m}{\sqrt{2}}$$

Root mean square (RMS) value of the output load voltage V_{RMS}

The root mean square (RMS) value of output load voltage in a full wave rectifier is

$$V_{RMS} = I_{RMS} R_L = \frac{I_m}{\sqrt{2}} R_L$$

Form factor

Form factor is the ratio of RMS value of current to the DC output current It can be mathematically written as

F.F = RMS value of current / DC output current

The form factor of a full wave rectifier is

F.F = 1.11

Advantages of full wave rectifier with centre tapped transformer

- High rectifier efficiency
- Full wave rectifier has high rectifier efficiency than the half wave rectifier. That means the full wave rectifier converts AC to DC more efficiently than the half wave rectifier.
- Low power loss
- In a half wave rectifier, only half cycle (positive or negative half cycle) is allowed and the remaining half cycle is blocked. As a result, more than half of the voltage is wasted. But in full wave rectifier, both half cycles (positive and negative half cycles) are allowed at the

same time. So no signal is wasted in a full wave rectifier.

- Low ripples
- The output DC signal in full wave rectifier has fewer ripples than the half wave rectifier.

Disadvantages of full wave rectifier with center tapped transformer

- High cost
- The centre tapped transformers are expensive and occupy a large space.

RC Coupled Amplifier

A Resistance Capacitance (RC) Coupled Amplifier is basically a multi-stage amplifier circuit extensively used in electronic circuits. Here the individual stages of the amplifier are connected together using a resistor–capacitor combinationdue to which it bears its name as RC Coupled. Figure 1 shows such a two-stage amplifier whose individual stages are nothing but the common emitter amplifiers. Hence the design of individual stages of the RC coupled amplifiers is similar to that in the case of common emitter amplifiers in which the resistors R1 and R2 form the biasing network while the emitter resistor RE form the stabilization network. Here the CE is also called bypass capacitor which passes only AC while restricting DC, which causes only DC voltage to drop across RE while the entire AC voltage will be coupled to the next stage.Further, the coupling capacitor CC also increases the stability of the network as it blocks the DC while offers a low resistance path to the AC signals, thereby preventing the DC bias conditions of one stage affecting the other. In addition, in this circuit, the drop across the collector-emitter terminal is chosen to be 50% of the supply voltage VCC in order to ensure appropriate biasing point.

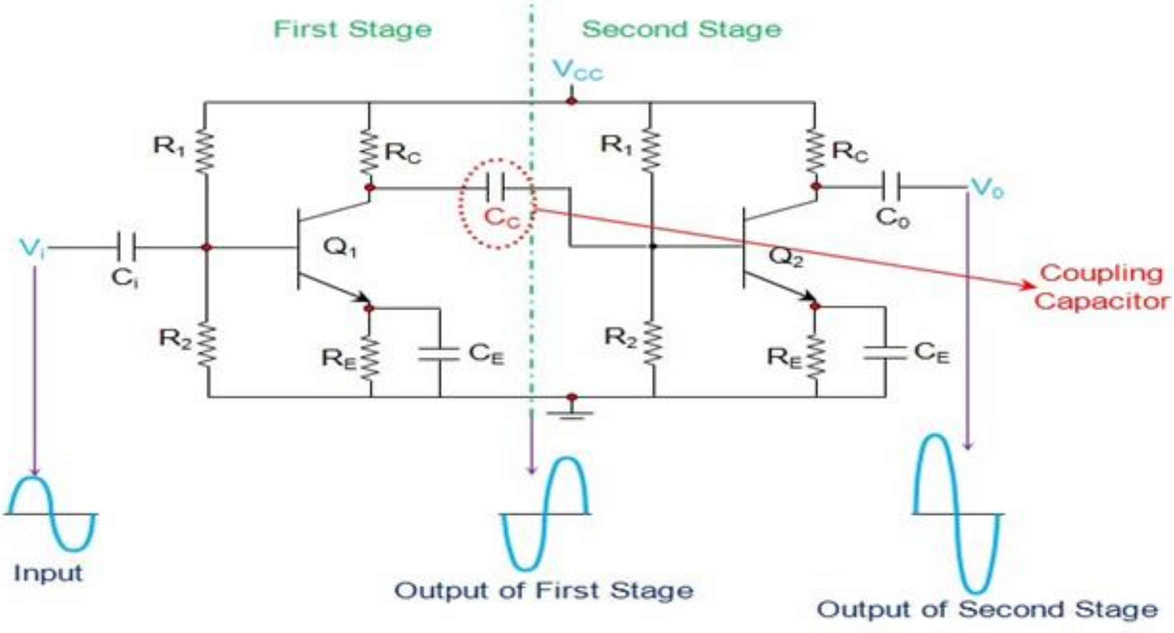


Fig 5.14**: Two stage RC Coupled amplifier**

In this kind of amplifier, the input signal applied at the base of the transistor in stage 1 (Q1) is amplified and appears at its collector terminal with a phase-shift of 180o.

The AC component of this signal is coupled to the second stage of the RC coupled amplifier through the coupling capacitor CC and thus appears as an input at the base of the second transistor Q2. This is further amplified and is passed-on as an output of the second stage and is available at the collector terminal of Q2 after being shift by 180o in its phase. This means that the output of the second stage will be 360o out-of-phase with respect to the input, which in turn indicates that the phase of the input signal and the phase of the output signal obtained at stage II will be identical.

Further it is to be noted that the cascading of individual amplifier stages increases the gain of the overall circuit as the net gain will be the product of the gain offered by the individual stages. However in real scenario, the net gain will be slightly less than this, due to the loading effect. In addition, it is important to note that by following the pattern exhibited by Figure 1, one can cascade any number of common emitter amplifiers but by keeping in mind that when the number of stages are even, the output will be in-phase with the input while if the number of stages are odd, then the output and the input will be out-of-phase.

The frequency response of a RC coupled amplifier (a curve of amplifier's gain v/s frequency), shown by Figure 2, indicates that the gain of the amplifier is constant over a wide range of mid-frequencies while it decreases considerably both at low and high frequencies. This is because, at low frequencies, the reactance of coupling capacitor CC is high which causes a small part of the signal to couple from one stage to the other. Moreover for the same case, even the reactance of the emitter capacitor CE will be high due to which it fails to shunt the emitter resistor RE effectively which in turn reduces the voltage gain.

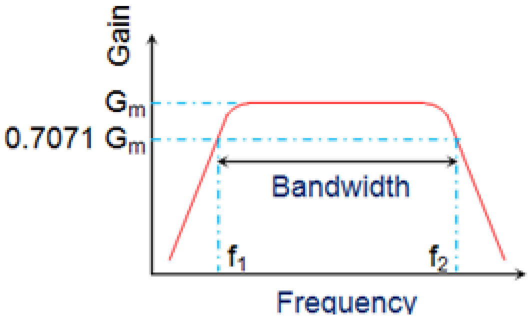


Fig 5.15**: Frequency Response of RC Coupled amplifier**

On the other hand, at high frequencies, the reactance of CC will be low which causes it to behave like a short circuit. This results in an increase in the loading effect of the next stage and thus reduces the voltage gain. In addition to this, for this case, the capacitive reactance of the base-emitter junction will be low. This results in a reduced voltage gain as it causes the base current to increase which inturn decreases the current amplification factor β. However, in mid-frequency range, as the frequency increases, the reactance of CC goes on decreasing which would lead to the increase in gain if not compensated by the fact that the reduction in reactance leads to an increase in the loading effect. Due to this reason, the gain of the amplifier remains uniform/constant throughout the mid-frequency band.

Advantages of RC Coupled Amplifier

- Cheap, economical and compact as it uses only resistors and capacitors.
- Offers a constant gain over a wide frequency band.

Disadvantages of RC Coupled Amplifier

- Unsuitable for low-frequency amplification.
- Low voltage and power gain as the effective load resistance (and hence the gain) is reduced due to the fact that the input of each stage presents a low resistance to its next stage.
- Moisture-sensitive, making them noisy as time elapses.
- Poor impedance matching as it has the output impedance several times larger than the device at its end- terminal (for example, a speaker in the case of a public address system).
- Narrow bandwidth when compared to JFET amplifier.

Applications of RC Coupled Amplifier

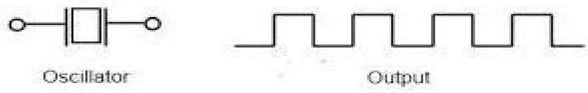
1. RF Communications.
2. Optical Fiber Communications.
3. Public address systems as pre-amplifiers.
4. Controllers.

5. Radio or TV Receivers as small signal amplifiers.

OSCILLATORS

Introduction

An oscillator is a circuit that produces a repetitive signal from a dc voltage. The feedback type oscillator which rely on a positive feedback of the output to maintain the oscillations. The relaxation oscillator makes use of an RC timing circuit to generate a non-sinusoidal signal such as square wave.



The requirements for oscillation are described by the Baukhausen criterion:
The magnitude of the loop gain Aβ must be 1
The phase shift of the loop gain A β must be 0^o or 360^o or integer multiple of 2pi

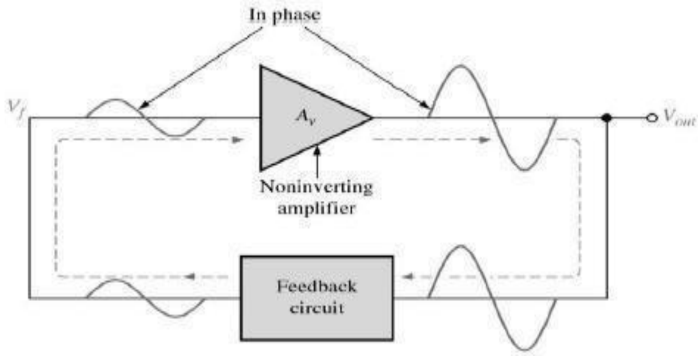


Fig 5.16: Oscillator Output
Amplitude stabilization

Amplitude stabilization:

- In both the oscillators above, the loop gain is set by component values
- In practice the gain of the active components is very variable
- If the gain of the circuit is too high it will saturate
- If the gain of the circuit is too low the oscillation will die

Real circuits need some means of stabilizing the magnitude of the oscillation to cope with variability in the gain of the circuit

Barkhausan criterion

The conditions for oscillator to produce oscillation are given by Barkhausan criterion. They are: The total phase shift produced by the circuit should be 360^o or 0^o

The Magnitude of loop gain must be greater than or equal to 1 (ie)$|A\beta|\geq 1$

In practice loop gain is kept slightly greater than unity to ensure that oscillator work even if there is a slight change in the circuit parameters

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 oscillation.

LC Oscillator:

Oscillators are used in many electronic circuits and systems providing the central “clock” signal that controls that controls the sequential operation of the entire system. Oscillators convert a DC input (the supply voltage) into an AC output (the waveform), which can have a wide range of different wave shapes and frequencies that can be either complicated in nature or simple sine waves depending upon the application.

Oscillators are also used in many pieces of test equipment producing sinusoidal sine wave, square, saw tooth or triangular shaped waveforms or just a train of pulse of a variable or constant width. LC Oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation.

An Oscillator is basically an Amplifier with “Positive Feedback”, or regenerative feedback (in-phase) and one of the many problems in electronic circuit design is stooping amplifiers from oscillating while trying to get oscillators to oscillate. Oscillators work because they overcome the losses of their feedback resonator circuit either in the form of a capacitor or both in the same circuit by applying DC energy at the required frequency into this resonator circuit.

In other words, an oscillator is an amplifier which uses positive feedback that generates an output frequency without the use of an input signal.

It is self sustaining. Then an oscillator has a small signal feedback amplifier with an open-loop gain equal to or slightly greater than one for oscillations to start but to continue oscillations the average loop gain must return to unity. In addition to these reactive components, an amplifying device such as an Operational Amplifier or Bipolar Transistors required. Unlike an amplifier there is no external AC input required to cause the Oscillator to work as the DC supply energy is converted by the oscillator into AC energy at the required frequency.

Basic Oscillator Feedback Circuit

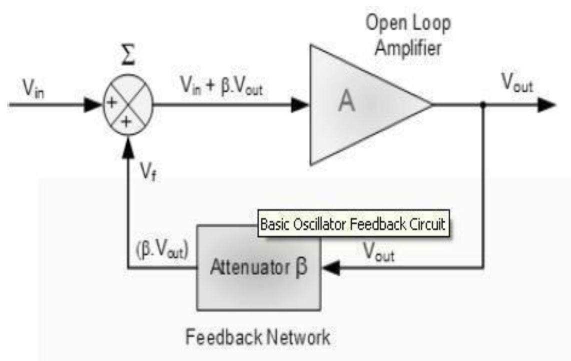


Fig 5.17: **Basic Oscillator Feedback Circuit**

Where: β is a feedback fraction.

$$\text{Gain, } A_v = \frac{V_{out}}{V_{in}} \qquad A = \text{open loop voltage gain}$$

$$A_v \times V_{in} = V_{out}$$

With Feedback

$$A_v(V_{in} - \beta V_{out}) = V_{out} \qquad \beta \text{ is the feedback fraction}$$

$$A_v.V_{in} - A_v.\beta.V_{out} = V_{out} \qquad A\beta = \text{the loop gain}$$

$$A_v.V_{in} = V_{out}(1 + A\beta) \qquad 1 + A\beta = \text{the feedback factor}$$

$$\therefore \frac{V_{out}}{V_{in}} = G_v = \frac{A}{1 + A\beta} \qquad G_v = \text{the closed loop gain}$$

Oscillators are circuits that generate a continuous voltage output waveform at a required frequency with the values of the inductors, capacitors or resistors forming a frequency selective LC resonant tank circuit and feedback network. This feedback network is an attenuation network which has a gain of less than one ($\beta<1$) and starts oscillations when $A\beta>1$ which returns to unity ($A\beta=1$) once oscillations commence. The LC oscillator's frequency is controlled using a tuned or resonant inductive/capacitive (LC) circuit with the resulting output frequency being known as the Oscillation Frequency.
By making the oscillators feedback a reactive network the phase angle of the feedback will vary as a function of frequency and this is called Phase-shift.

There are basically types of Oscillators:

1. **Sinusoidal Oscillators** - these are known as Harmonic Oscillators and are generally a: LC Tuned-feedback" or "RC tuned-feedback" type Oscillator that generates a purely sinusoidal waveform which is of constant amplitude and frequency.

2. **Non-Sinusoidal Oscillators** – these are known as Relaxation Oscillators and generate complex non- sinusoidal waveforms that changes very quickly from one condition of stability to another such as "Square-wave", "Triangular- wave" or "Saw-toothed-wave" type waveforms.

- **Resonance**

When a constant voltage but of varying frequency is applied to a circuit consisting of an inductor, capacitor and resistor the reactance of both the Capacitor/Resistor and Inductor/Resistor circuits is to change both the amplitude and the phase of the output signal due to the reactance of the components used.

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, (fr) 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. Consider the circuit below.

- **Basic LC Oscillator Tank Circuit**

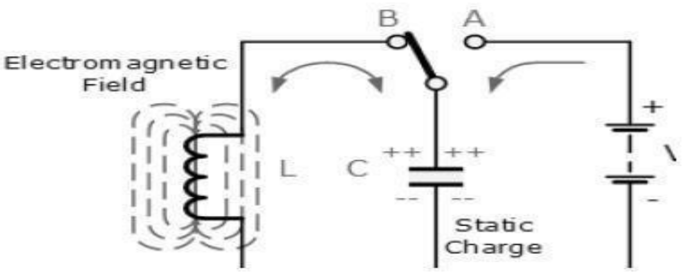


Fig 5.18: **Basic LC Oscillator Tank Circuit**

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 electromagnetic 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 an electromagnetic field around the coil which resists this flow of current. When the capacitor, C is completely discharged the energy that was originally stored in the capacitor, C as an electrostatic filed is now stored in the inductive coil, L as an electromagnetic 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 electromagnetic field begins to collapse. A back emf is induced in the coil ($e= -Ldi/dt$) keeping the current flowing in the original direction. This current now charges up the capacitor, c with the opposite polarity to its original charge.

C continues to chare 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 os 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.

This then forms the basis of an LC oscillator's tank circuit and theoretically this cycling back and forth will continue indefinitely. However, every time energy is transferred from C to L or from L to C losses occur which decay the oscillations.

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. Electrical energy is lost in the DC or real resistance of the inductors coil, in the dielectric of the capacitor, and in radiation from the circuit so the oscillation steadily decreases until they die away completely and the process stops.

- **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 fr 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 (fr) 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.

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. This process can be achieved using a voltage amplifier using an op- amp, FET or bipolar transistor as its active device.

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. To produce a constant oscillation, the level of the energy fed back to the LC network must be accurately controlled.

Then there must be some form of automatic amplitude or gain control 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. Consider the circuit below.

Basic Transistor LC Oscillator Circuit

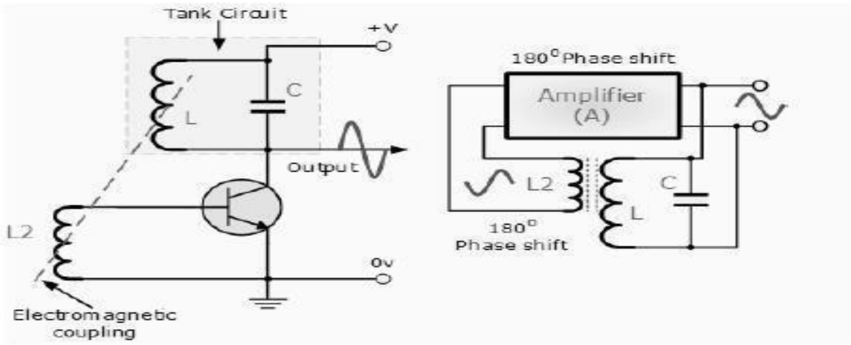


Fig 5.19: **Basic Transistor LC Oscillator Circuit**

A Bipolar Transistor is used as the LC oscillator's amplifier with the tuned LC tank circuit acts as the collector load. Another coil L2 is connected between the base and the emitter of the transistor whose electromagnetic field is "mutually" coupled with that of coil L. Mutual inductance exists between the two circuits.

The changing current flowing in one coil circuit induces, by electromagnetic induction, a potential voltage in the other (transformer effect) so as the oscillations occur in the tuned circuit, electromagnetic energy is transferred from coil L to coil L2 and a voltage of the same frequency as that in the tuned circuit is applied between the base and emitter of the transistor.

In this way the necessary automatic feedback voltage is applied to the amplifying transistor. The amount of feedback can bre increased or decreased by altering the coupling between the two Coils L and L2. When the circuit is oscillating its impedance is resistive and the collector and base voltages are 180 out of phase. In order to maintain oscillations (called frequency stability) the voltage applied to the tuned circuit must be "in-phase" with the oscillations occurring in the tuned circuit.

Therefore, we must introduce an additional 180^o phase shift into the feedback path between the collector and the base. This is achieved by winding the coil of L2 in the correct direction relative to coil L giving us the correct amplitude and phase relationships for the Oscillators circuit or by connecting a phase shift network between the output and input of the amplifier.

The LC Oscillator is therefore a "Sinusoidal Oscillator" or a "Harmonic Oscillator" as it is more commonly called. LC oscillators can generate high frequency sine waves for use in radio frequency (RF) type applications with the transistor amplifier being of a Bipolar Transistor or FET.Harmonic Oscillators come in many different forms because there are many different ways to construct an LC filter network and amplifier with the most common being the Hartley LC Oscillator**,** Colpitts LC Oscillator**,** Armstrong Oscillator and Clapp Oscillator to name a few.

The Hartley Oscillator

The main disadvantages of the basic LC Oscillator circuit we looked at in the previous tutorial is that they have no means of controlling the amplitude of the oscillations and also, it is difficult to tune the oscillator to the required frequency. However, it is possible to feed back exactly the right amount of voltage for constant amplitude oscillations. If we feed back more than is necessary the amplitude of the oscillations can be controlled by biasing the amplifier in such a way that if the oscillations increase in amplitude, the bias is increased and the gain of the amplifier is reduced.

If the amplitude of the oscillations decreases the bias decreases and the gain of the amplifier increases, thus increasing the feedback. In this way the amplitude of the oscillations are kept constant using a process known as Automatic Base Bias**.**

One big advantage of automatic base bias in a voltage controlled oscillator, is that the oscillator can be made more efficient by providing a Class-B bias or even a Class-C bias condition of the transistor. This has the advantage that the collector current only flows during part of the oscillation cycle so the quiescent collector current is very small.

Then this "self-tuning" base oscillator circuit forms one of the most common types of LC parallel resonant feedback oscillator configurations called the Hartley Oscillator circuit.

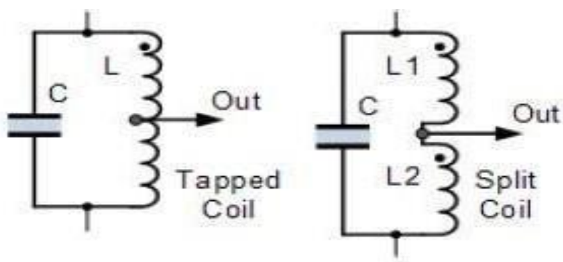


Fig 5.20: Hartley Oscillator Tuned Circuit

In the Hartley Oscillator the tuned LC circuit is connected between the collector and the base of the transistor amplifier. As far as the oscillatory voltage is concerned, the emitter is connected to a tapping point on the tuned circuit coil. The feedback of the tuned tank circuit is taken from the centre tap of the inductor coil or even two separate coils in series which are in parallel with a variable capacitor, C as shown.The Hartley circuit is often referred to as a split- inductance oscillator because coil L is centre-tapped. In effect, inductance L acts like two separate coils in very close proximity with the current flowing through coil section XY induces a signal into coil section YZ below.A 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.

Basic Hartley Oscillator Circuit

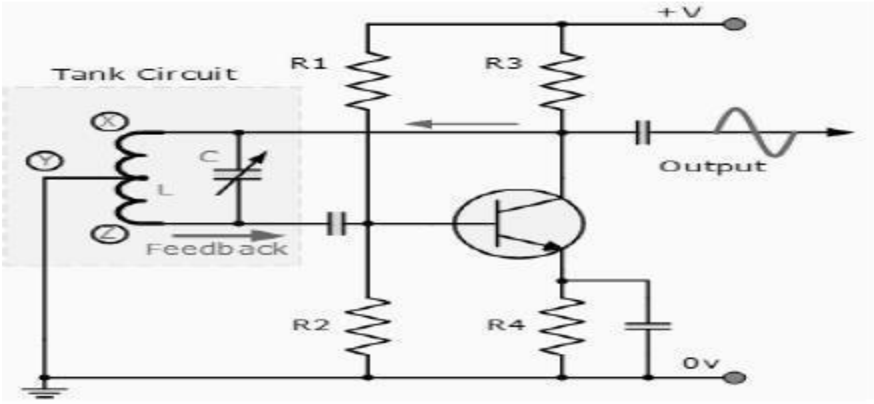


Fig 5.21: Basic Hartley Oscillator Circuit

When the circuit is oscillating, the voltage at point X (collector), relative to point Y (emitter), is 180 degree out- of-phase with the voltage at point Z(base) relative to point Y. 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 and along with the original 180 phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained. 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. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors.

In this Hartley Oscillator circuit, the DC Collector current flows through part of the coil and for this reason the circuit is said to be "Series-fed" with the frequency of oscillation of the Hartley Oscillator being given as.

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

where: $L_T = L_1 + L_2 + 2M$

The frequency of oscillations can be adjusted by varying the "tuning" capacitor, C or by varying the position of the iron-dust core inside the coil (inductive tuning) giving an output over a wide range of frequencies making it very easy to tune. Also the Hartley Oscillator produces output amplitude which is constant over the entire frequency range.

As well as the Series-fed Hartley Oscillator above, it is also possible to connect the tuned tank circuit across the amplifier as a shunt-fed oscillator as shown below.

The Colpitts Oscillator

The Colpitts Oscillator, named after its inventor Edwin Colpitts is another type of LC oscillator design. In many ways, the Colpitts oscillator is the exact opposite of the Hartley Oscillator we looked at in the previous tutorial. Just like the Hartley oscillator, the tuned tank circuit consists of an LC resonance sub-circuit connected between the collector and the base of a single stage transistor

amplifier producing a sinusoidal output waveform.
The basic configuration of the Colpitts Oscillator resembles that of the Hartley Oscillator but the difference this time is that the centre tapping of the tank sub-circuit is now made at the junction of a "capacitive voltage divider" network instead of a tapped autotransformer type inductor as in the Hartley oscillator.

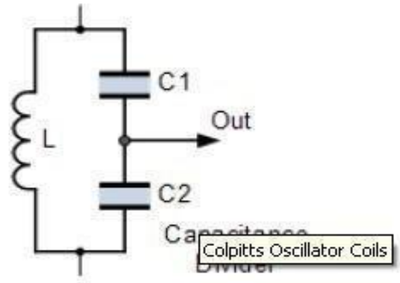


Fig 5.22: The Colpitts Oscillator

Colpitts Oscillator Circuit

The Colpitts oscillator uses a capacitor voltage divider as its feedback source.

The two capacitors, C1 and C2 are placed across a common inductor, L as shown so that C1, C2 and L forms the tuned tank circuit the same as for the Hartley oscillator circuit. The advantage of this type of tank circuit configuration is that with less self and mutual inductance in the tank circuit, frequency stability is improved along with a more simple design. As with the Hartley oscillator, the colpitts oscillator uses a single stage bipolar transistor amplifier as the gain element which produces a sinusoidal output. Consider the circuit below.

Basic Colpitts Oscillator Circuit

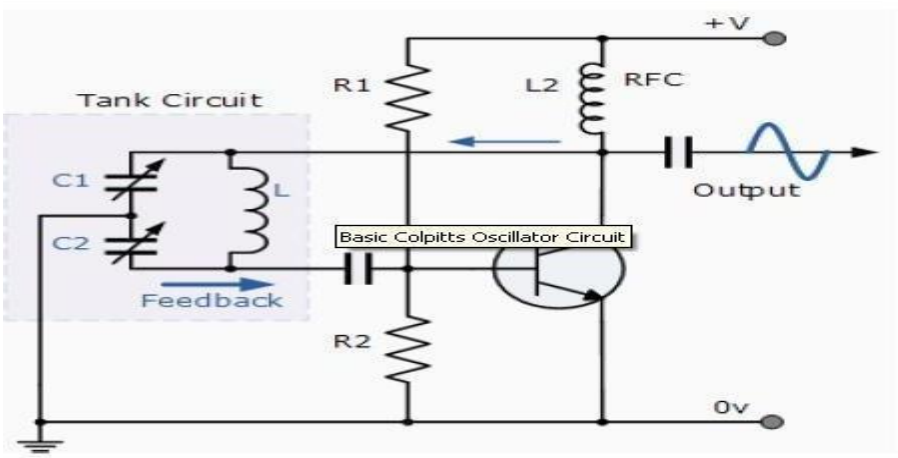


Fig 5.23: Basic Colpitts Oscillator Circuit

The transistor amplifiers emitter is connected to the junction of capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is firstly applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to the base-emitter junction and appear in the amplified at the collector output. The amount of feedback depends on the values of C1 and C2 with the smaller the values of C the greater will be the feedback.

The required external phase shift is obtained in a similar manner to that in the Hartley oscillator circuit with the required positive feedback obtained for sustained un-damped oscillations. The amount of feedback is determined by the ratio of C1 and C2 which are generally "ganged" together to provide a constant amount of feedback so as one is adjusted the other automatically follows.

The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

$$f_r = \frac{1}{2\pi\sqrt{L\,C_T}}$$

where C_T is the capacitance of C1 and C2 connected in series and is given as:.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

The configuration of the transistor amplifier is of a Common Emitter Amplifier with the output signal 180^o out of phase with regards to the input signal. The additional 180^o phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360^o. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitor acts as a DC- blocking capacitors. The radio-frequency choke (RFC) is used to provide a high reactance (ideally open circuit) at the frequency of oscillation, (fr) and a low resistance at DC.

RC Phase-Shift Oscillator

In a RC Oscillator the input is shifted 180^o through the amplifier stage and180^o again through a second inverting stage giving us "$180^o + 180^o = 360^o$" of phase shift which is the same as 0^o 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, for example.

RC Phase-Shift Network

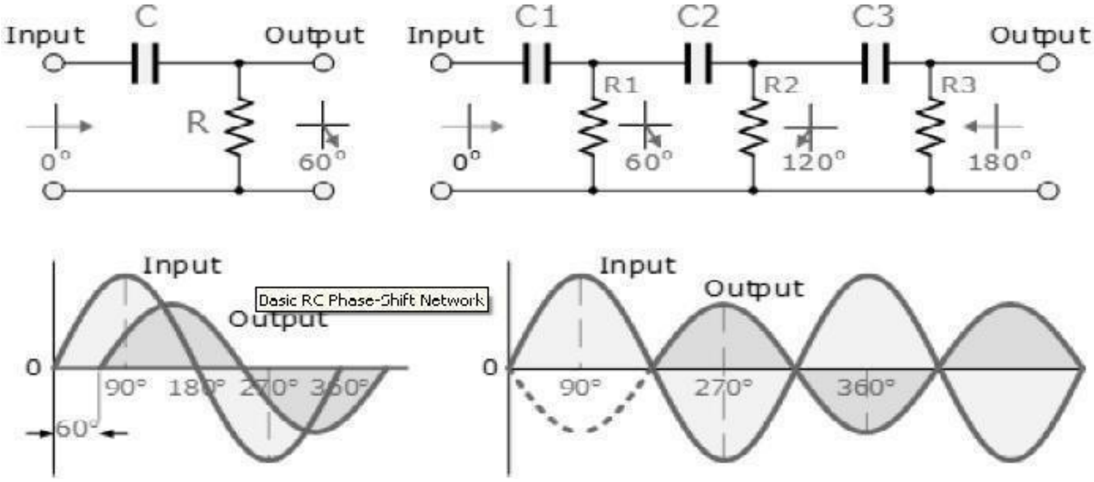


Fig 5.24: RC Phase-Shift Network

The circuit on the left shows a single resistor -capacitor network and whose output voltage "leads" the input voltage by some angle less than 90 °. An ideal RC circuit would produce a phase shift of exactly 90 degree. The amount of actual phase shift in the circuit depends upon the values of the resistor and the capacitor,the chosen frequency of oscillations with the phase angle (Φ) being given as:

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

RC Oscillator Circuit

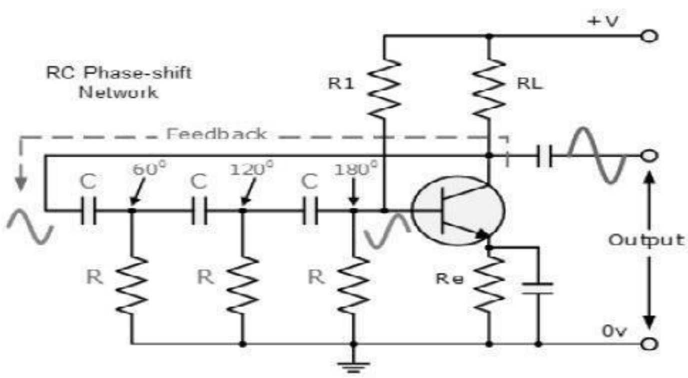


Fig 5.25: RC Oscillator Circuit

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

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:

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

WIEN BRIDGE OSCILLATOR

One of the simplest sine wave oscillators which uses a RC network in place of the conventional LC tuned tank circuit to produce a sinusoidal output waveform, is the Wien Bridge Oscillator.The Wien Bridge Oscillator is so called because the circuit is based on a frequency-selective form of the Whetstone 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

Wien Bridge Oscillator

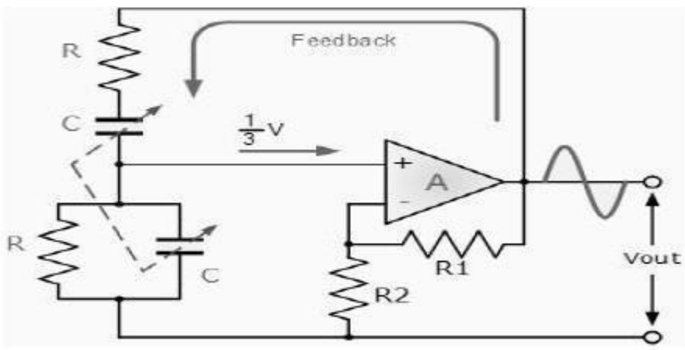


Fig 5.26: **Wien Bridge Oscillator**

The output of the operational amplifier is fed back to both the inputs of the amplifier. One part of the feedback signal is connected to the inverting input terminal (negative feedback) via the resistor divider network of R1 and R2 which allows the amplifiers voltage gain to be adjusted within narrow limits. The other part is fed back to the non- inverting input terminal (positive feedback) via the RC Wien Bridge network. The RC network is connected in the positive feedback path of the amplifier and has zero phase shift a just one frequency. Then at the selected resonant frequency, (fr) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" so the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.

Also the voltage gain of the amplifier circuit MUST be equal to three "Gain =3" for oscillations to start. This value is set by the feedback resistor network, R1 and R2 for an inverting amplifier and is given as the ratio -R1/R2.also due to the open loop gain limitations of operational amplifiers; frequencies above 1MHZ are unachievable without the use of special high frequency op-amps. Then for oscillations to occur in a weinbridge oscillator circuit the following conditions must apply.

1. With no input signal the Wien Bridge Oscillator produces output oscillations.

2. The Wien Bridge Oscillator can produce a large range of frequencies.

3. The Voltage gain of the amplifier must be at least 3.

4. The network can be used with a Non-inverting amplifier.

5. The input resistance of the amplifier must be high compared to R so that the RC network is not overloaded and alter the required conditions.

6. The output resistance of the amplifier must be low so that the effect of external loading is minimized.

7. Some method of stabilizing the amplitude of the oscillations must be provided because if the voltage gain of the amplifier is too small the desired oscillation will decay and stop and if it is too large the output amplitude rises to the value of the supply rails, which saturates the op-amp and causes the output waveform to become distorted.

8. With amplitude stabilization in the form of feedback diodes, oscillations from the oscillator can go on indefinitely.

9. Frequency of oscillation $F=1/2*\pi*RC$