UNIT 2

Oscillators

Introduction to Feedback:

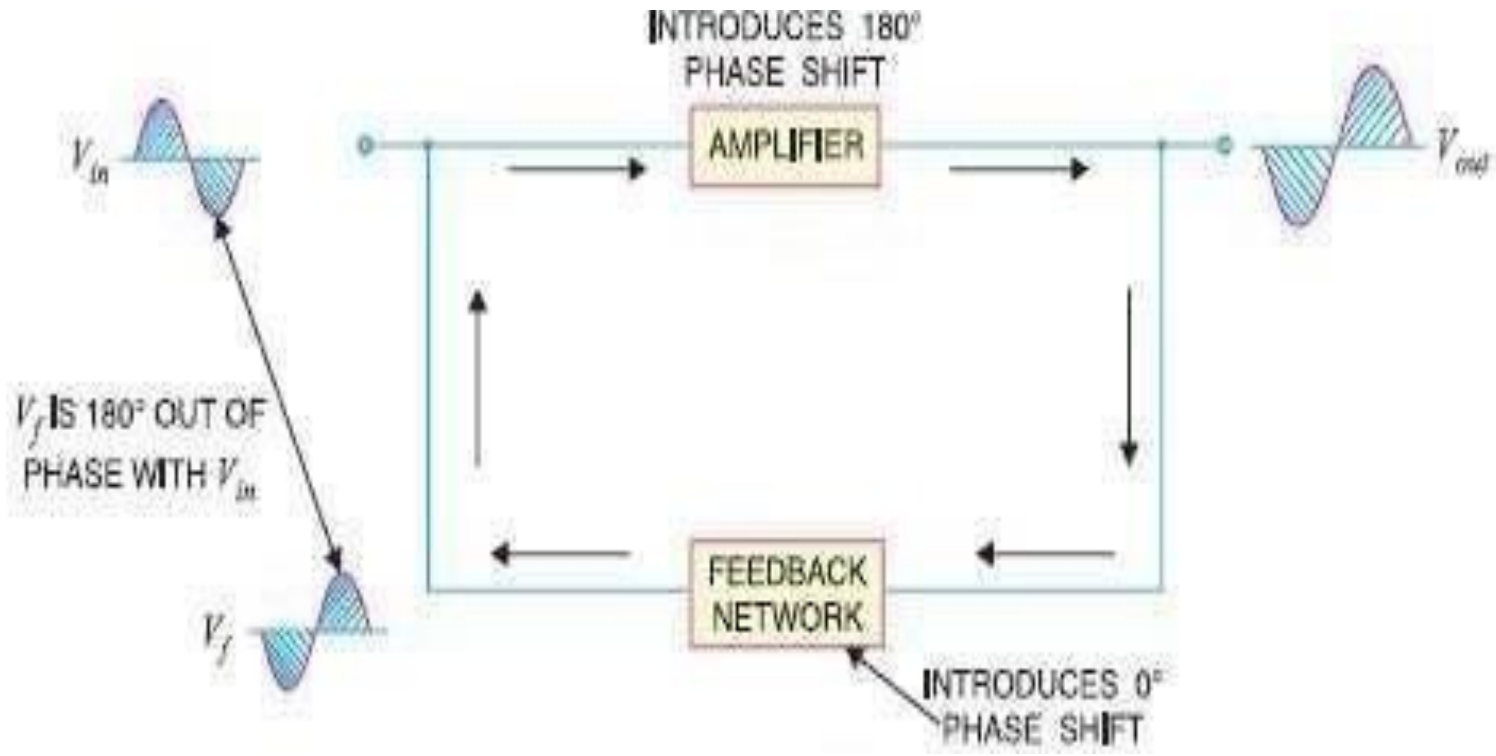
The phenomenon of feeding a portion of the output signal back to the input circuit is known as feedback. The effect results in a dependence between the output and the input and an effective control can be obtained in the working of the circuit. Feedback is of two types.

- Negative Feedback
- Positive Feedback

Negative or Degenerate feedback:

- In negative feedback, the feedback energy (voltage or current), is out of phase with the input signal and thus opposes it.
- Negative feedback reduces gain of the amplifier. It also reduce distortion, noise and instability.
- This feedback increases bandwidth and improves input and output impedances.
- Due to these advantages, the negative feedback is frequently used in amplifiers.

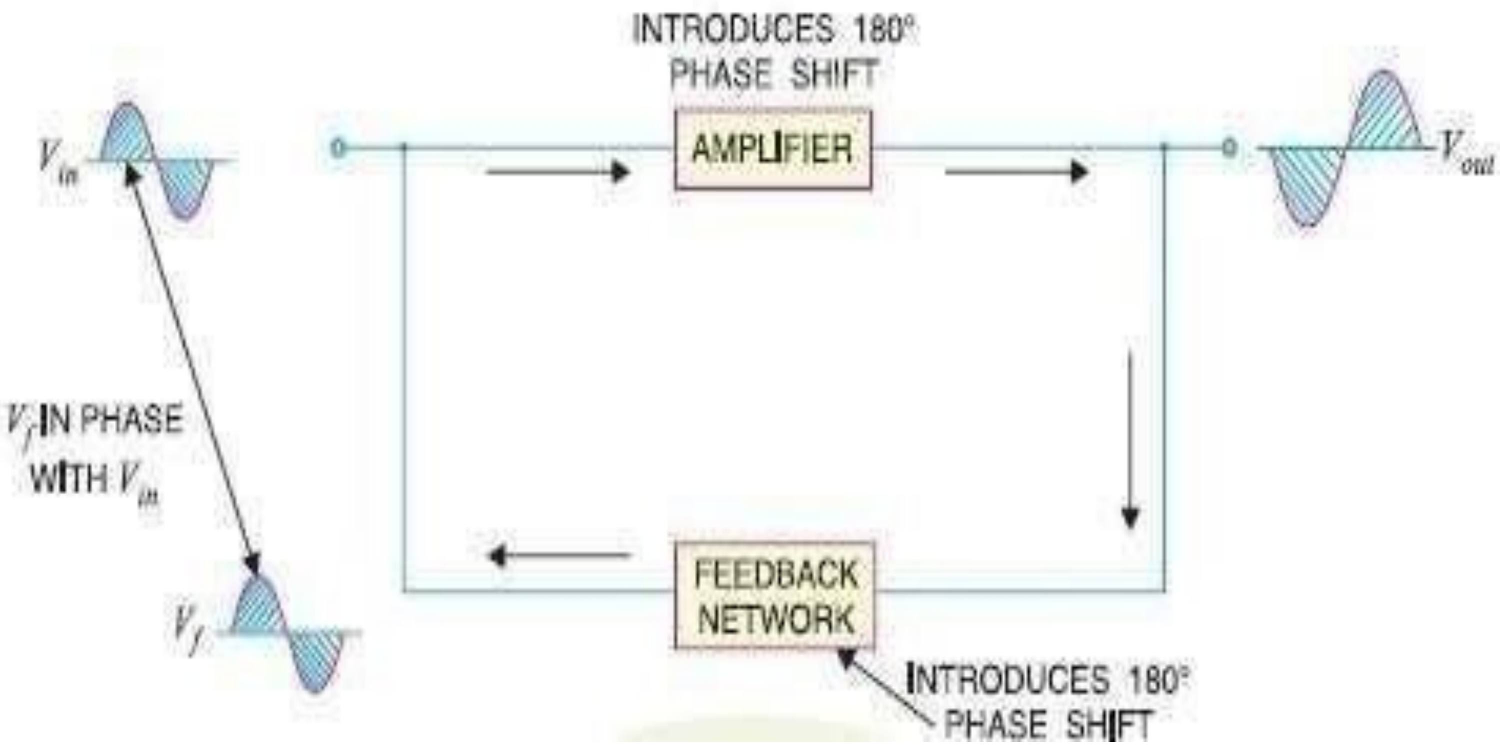
Negative Feedback



Positive or regenerate feedback:

- In positive feedback, the feedback energy (voltage or currents), is in phase with the input signal and thus aids it. Positive feedback increases gain of the amplifier also increases distortion, noise and instability.
- Because of these disadvantages, positive feedback is seldom employed in amplifiers. But the positive feedback is used in oscillators.

Positive Feedback



In the above figure, the gain of the amplifier is represented as A. The gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i. The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is subtracted for negative feedback, from the signal voltage V_s. Now,

$$\mathbf{Vi = Vs + V_f = Vs + \beta Vo}$$

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

The output V_o must be equal to the input voltage (V_s + βV_o) multiplied by the gain A of the amplifier.

Hence,

$$(Vs+\beta Vo)A=Vo$$

$$AVs+A\beta Vo=Vo$$

$$AVs=Vo(1-A\beta)$$

$$Vo/Vs=A/(1-A\beta)$$

Therefore, the gain of the amplifier with feedback is given by

$$A_f = A/(1-A\beta)$$

Comparison Between Positive and Negative Feed Back:

S.No.	Negative Feedback	Positive Feedback
1.	Feedback energy is out phase with their input signal	Feedback energy is in phase with the input signal.
2.	Gain of the amplifier decreases	Gain of the amplifier increases
3.	Gain stability increases	Gain stability decreases
4.	Noise and distortion decreases.	Noise and distribution increases.
5.	Increase the band width	Decreases bandwidth
6.		Used in Oscillators

Used in amplifiers

Barkhausen Criteria:

- The condition **Aβ=1** is known as Barkhausen criteria. It implies

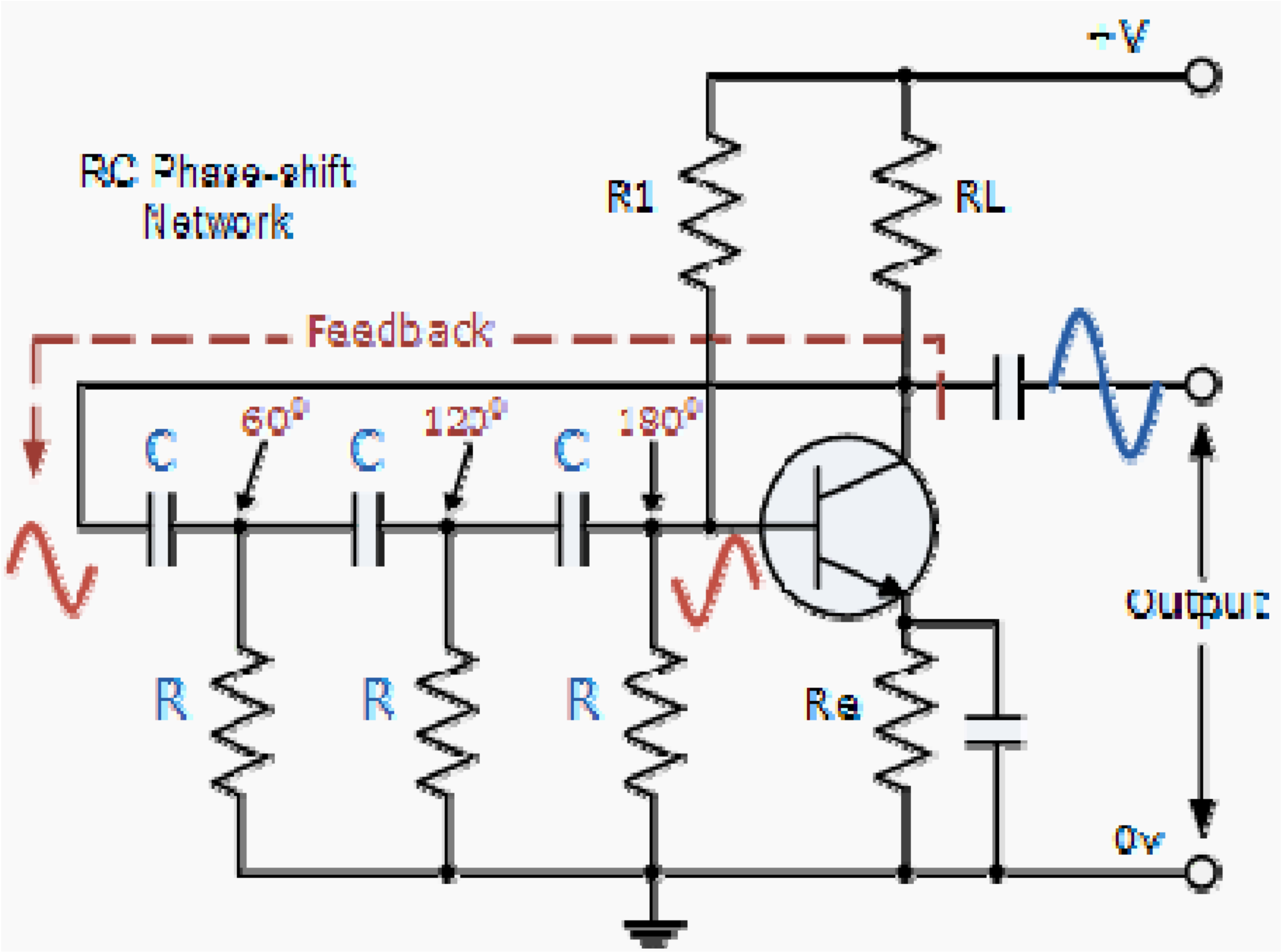
(1) Magnitude of the loop gain **Aβ = 1**

(2) Phase shift over the loop = 0 0r 360 degrees.

- Frequency of the noise in the amplifier for which this criteria are satisfied, is the frequency of oscillations.

- By applying this criteria, we can even find the values of transistor parameters, like gain, required for setting in oscillations.

Basic RC Phase Shift Oscillator:



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:

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

Where:

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)

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.

Type of Oscillator:

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**.

The main types of Oscillators include:

RC Oscillators

- Wien Bridge Oscillator
- RC Phase Shift Oscillator

LC Oscillators

- Hartley Oscillator
- Colpitts Oscillator
- Clapp Oscillator

Crystal Oscillators

Wien Bridge Oscillator:

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.

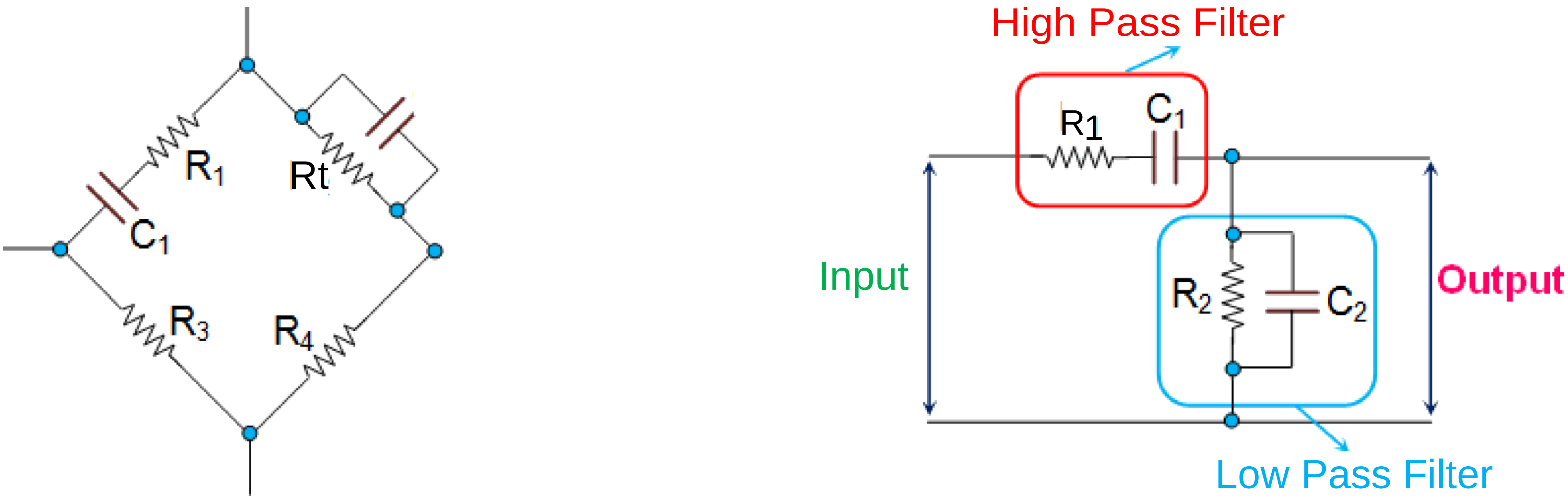


Figure 1 (a) Wien-Bridge Network (b) Two arms of the Wien-Bridge Network

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.

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

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

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

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

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:

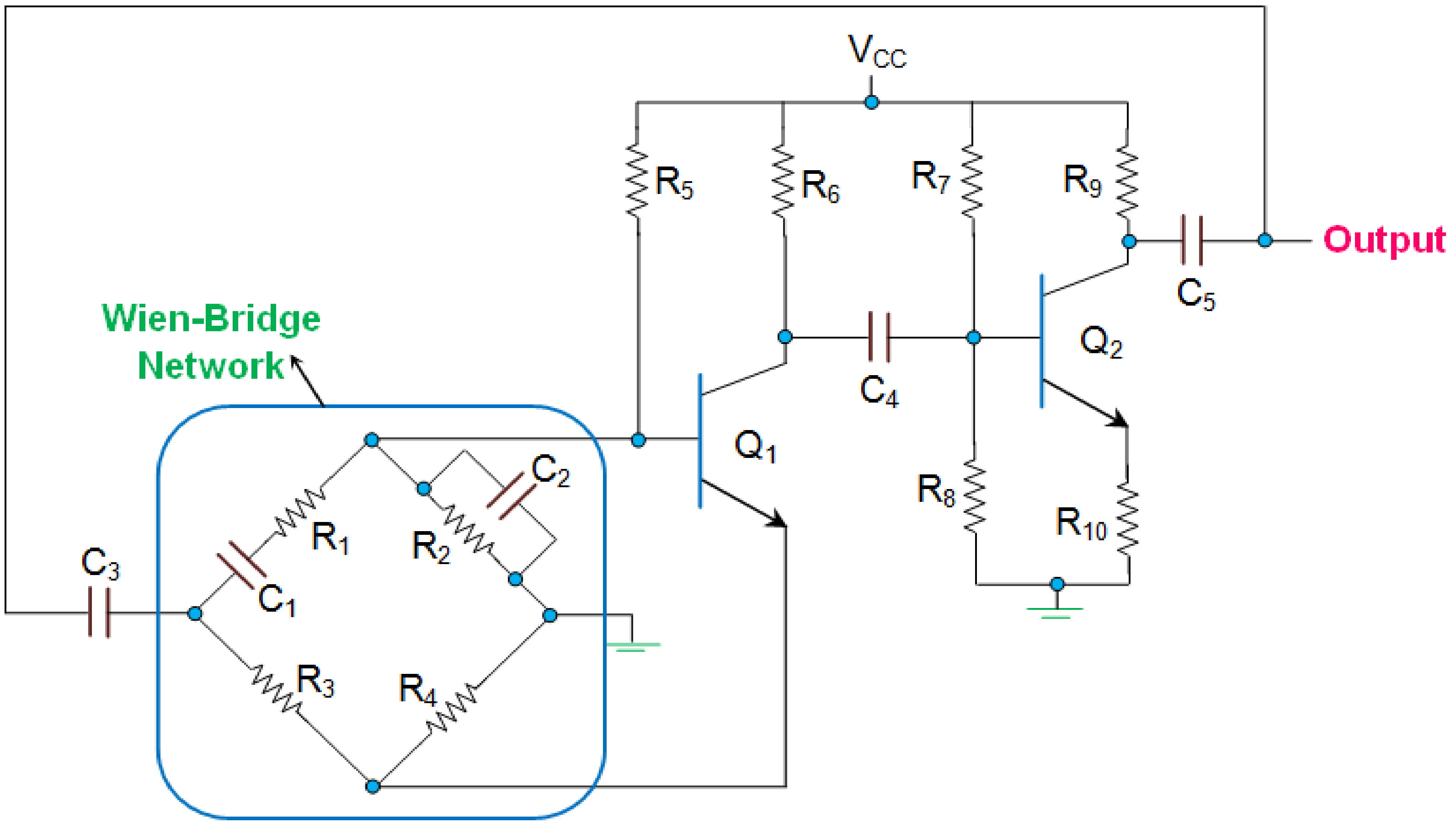


Figure 2 Wien-Bridge Oscillator Using BJT

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.

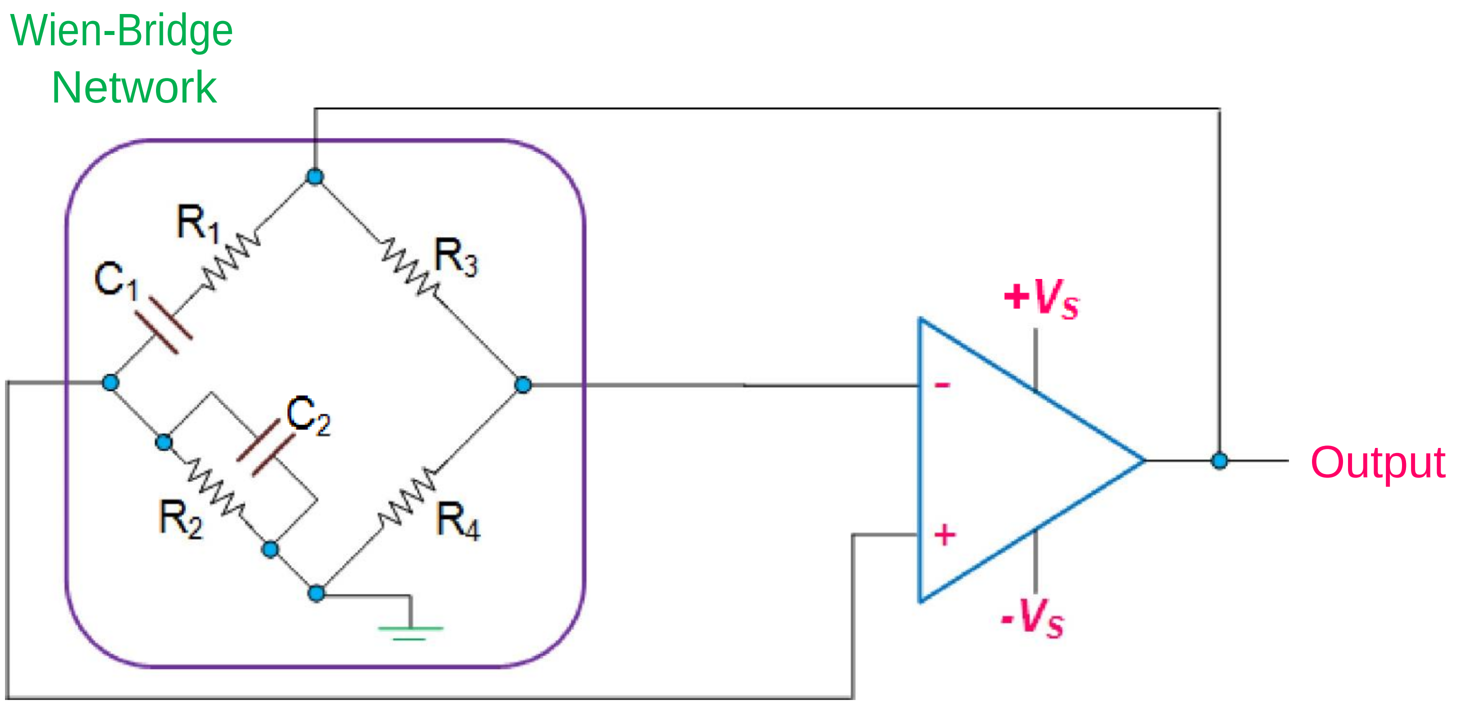


Figure 3 Wien-Bridge Oscillator Using an Op-Amp

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.

RC Phase Shift Oscillator:

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.

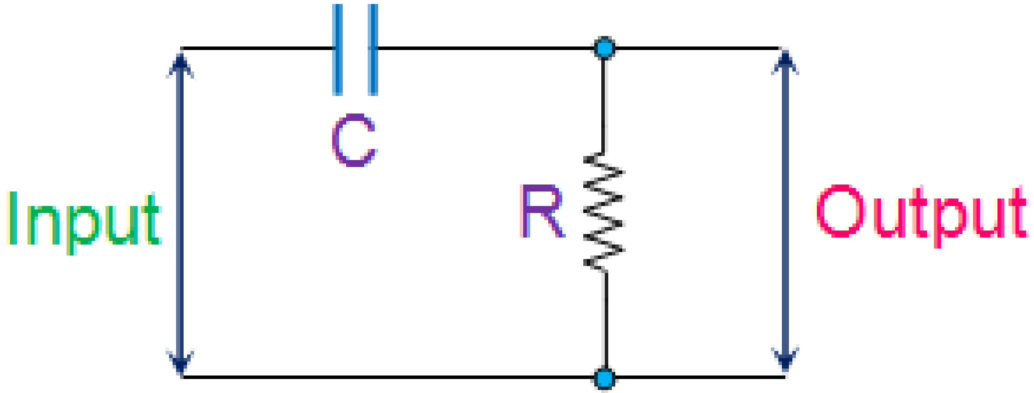


Figure 1 RC Phase-Shift Network

Ideally a simple RC network is expected to have an output which leads the input by 90^{o}. 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 60º, as shown by Figure 2.

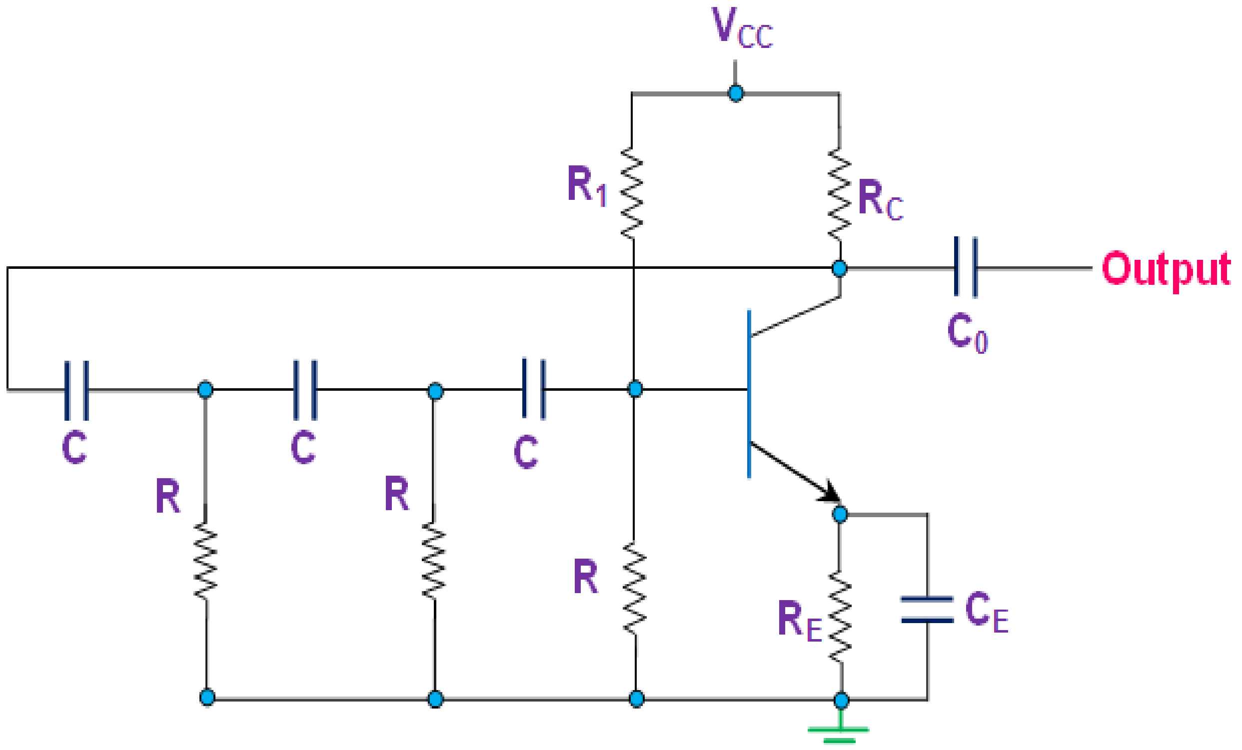


Figure 2 RC Phase-Shift Oscillator Using BJT

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^o during its course of travel from output terminal to the base of the transistor. Next, this signal will be shifted again by 180^o by the transistor in the circuit due to the fact that the phase-difference between the input and the output will be 180^o in the case of common emitter configuration. This makes the net phase-difference to be 360^o, 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 360^{o} is offered collectively by the RC phase-shift networks and the [Op-Amp]() working in inverted configuration.

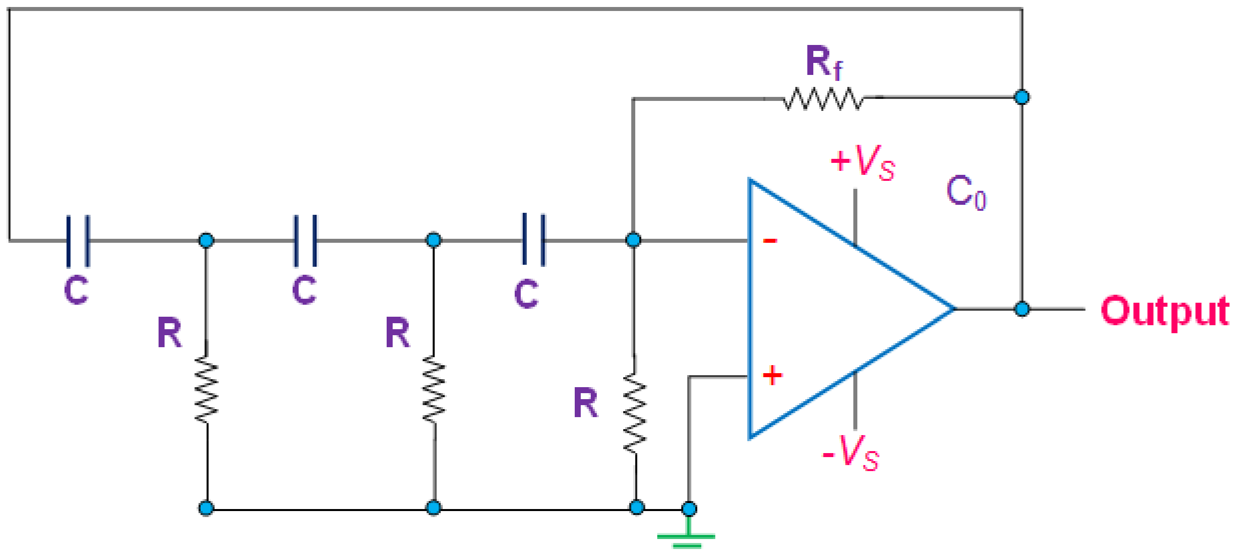


Figure 3 RC Phase-Shift Oscillator Using an Op-Amp

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.

LC- Oscillators

LC Oscillator	Z1	Z2	Z3
Hartley Oscillator	L	L	C
Colpitts Oscillator	C	C	L
Clapp Oscillator	C	C	L-C

Hartley Oscillator:

Hartley Oscillator is a type of harmonic oscillator which was invented by Ralph Hartley in 1915. These are the Tuned Circuit Oscillators which are used to produce the waves in the range of **radio frequency and hence are also referred to as RF Oscillators**. Its frequency of oscillation is decided by its tank circuit which has a capacitor connected in parallel with the two serially connected inductors, as shown by Figure 1.

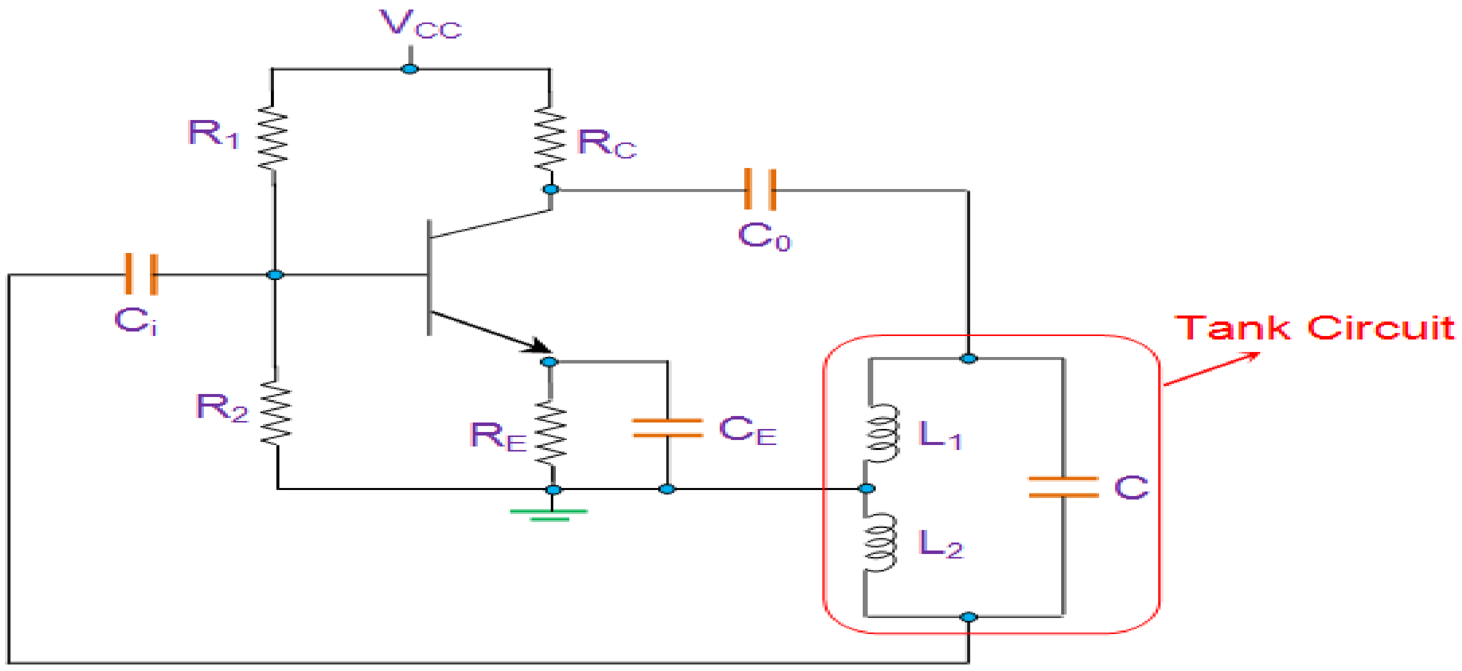


Figure 1 Hartley Oscillator

Here the R_C is the collector resistor while the emitter resistor R_E forms the stabilizing network. Further the resistors R_1 and R_2 form the voltage divider bias network for the transistor in common-emitter CE configuration. Next, the capacitors C_i and C_o are the input and output decoupling capacitors while the emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals. All these components are identical to those present in the case of a common-emitter amplifier which is biased using a voltage divider network. However, Figure 1 also shows one more set of components viz., the inductors L_1 and L_2 and the capacitor C which form the tank circuit (shown in red enclosure).

On switching ON the power supply, the transistor starts to conduct, leading to an increase in the collector current, I_C which charges the capacitor C. On acquiring the maximum charge feasible, C starts to discharge via the inductors L_1 and L_2. This charging and discharging cycles result in the damped oscillations in the tank circuit. The oscillation current in the tank circuit produces an AC voltage across the inductors L_1 and L_2 which are out of phase by 180^o as their point of contact is grounded.

Further from the figure, it is evident that the output of the amplifier is applied across the inductor L_1 while the feedback voltage drawn across L_2 is applied to the base of the transistor. Thus one can conclude that the output of the amplifier is in-phase with the tank circuit's voltage and supplies back the energy lost by it while the energy fed back to amplifier circuit will be out-of-phase by 180^o. The feedback voltage which is already 180^o out-of-phase with the transistor is provided by an additional 180^o phase-shift due to the transistor action. Hence the signal which appears at the transistor's output will be amplified and will have a net phase-shift of 360^o.

At this state, if one makes the gain of the circuit to be slightly greater than the feedback ratio given by

$$\beta = \frac{L_1}{L_2};\ \textit{if the coils are wound on different cores}$$

$$\beta = \frac{L_1 + M}{L_2 + M}$$

(if the coils are wound on the same core with M indicating the mutual inductance)

then the circuit generates the oscillations which can be sustained by maintaining the gain of the circuit to be equal to that of the feedback ratio. This causes the circuit in Figure 1 to act as an oscillator as it would then satisfy both the conditions of the Barkhausen criteria.

The frequency of such an oscillator is given as

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

Where,

$$L_{eff}\ \textit{is the effective series inductance which is expressed as}$$

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

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

Hartley oscillators are available in many different configurations including series-or shunt-fed, common-emitter or common-base configured, and BJT (Bipolar Junction Transistor) or FET (Field Effect Transistor) amplifier based. Further it is to be noted that the transistor-based amplifier section of Figure 1 can even be replaced by an amplifier of any other kind like that of an inverting amplifier formed by an Op-Amp as shown by Figure 2. The working of this kind of oscillator is similar to that of the one shown earlier. However, here, the gain of the oscillator can be individually adjusted using the feedback resistor R_f due to the fact that the gain of the inverting amplifier is given as $-R_f / R_1$. From this, it can be noted that, in this case, the gain of the circuit is less dependent on the circuit elements of the tank circuit. This increases the stability of the oscillator in terms of its frequency.

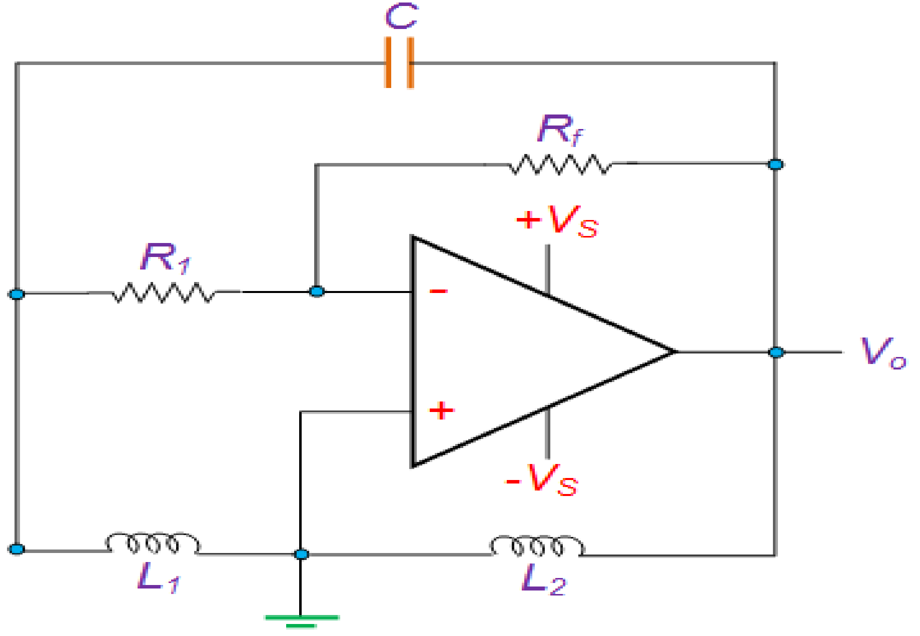


Figure 2 Hartley Oscillator Using an Op-Amp

Hartley Oscillators are advantageous as **they are easy-tunable circuits** with a very few components including a capacitor and either two inductors or a tapped coil. This results in a constant amplitude output throughout its wide operational frequency range which typically **ranges from 20 KHz to 30 MHz.** However, this kind of oscillator is **not suitable for low frequency as it would result in a large-sized inductor which makes the circuit bulky**. Further, the output of **Hartley Oscillator** has high content of harmonics in it and hence does not suit for the applications which require pure sine wave.

Colpitts Oscillator:

Colpitts Oscillator is a type of LC oscillator which falls under the category of Harmonic Oscillator and was invented by Edwin Colpitts in 1918. Figure 1 shows a typical Colpitts oscillator with a tank circuit in which an inductor L is connected in parallel to the serial combination of capacitors C_1 and C_2 (shown by the red enclosure).

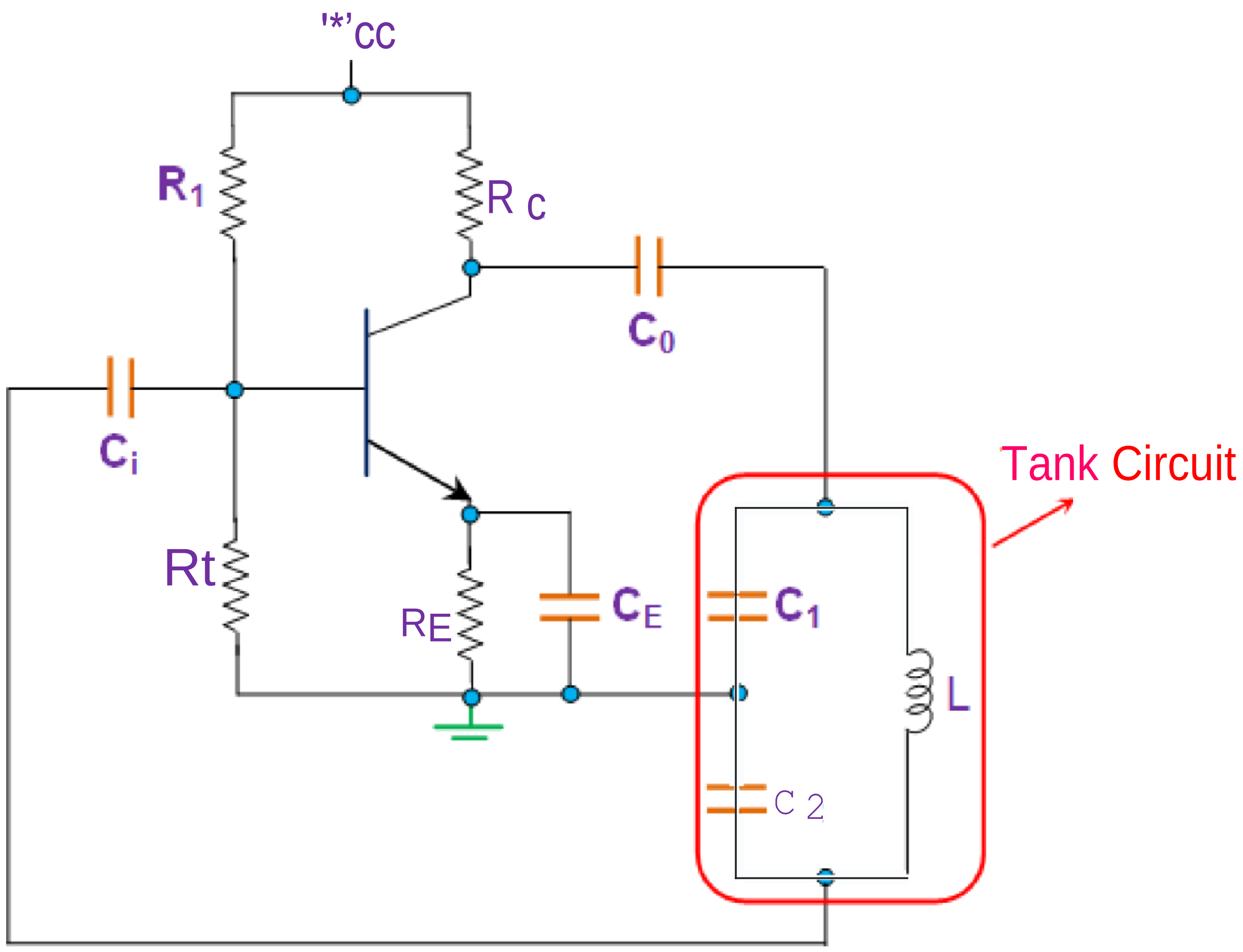


Figure 1 Colpitts Oscillator

Other components in the circuit are the same as that found in the case of common-emitter CE which is biased using a voltage divider network i.e. R_C is the collector resistor, R_E is the emitter resistor which is used to stabilize the circuit and the resistors R_1 and R_2 form the voltage divider bias network. Further, the capacitors C_i and C_o are the input and output decoupling capacitors while the emitter capacitor C_E is the bypass capacitor used to bypass the amplified AC signals.

Here, as the power supply is switched ON, the transistor starts to conduct, increasing the collector current I_C due to which the capacitors C_1 and C_2 get charged. On acquiring the maximum charge feasible, they start to discharge via the inductor L. During this process, the electrostatic energy stored in the capacitor gets converted into magnetic flux which in turn is stored within the inductor in the form of electromagnetic energy. Next, the inductor starts to discharge which charges the capacitors once again. Likewise, the cycle continues which gives rise to the oscillations in the tank circuit.

Further the figure shows that the output of the amplifier appears across C_1 and thus is in-phase with the tank circuit's voltage and makes-up for the energy lost by re-supplying it. On the other hand, the voltage feedback to the transistor is the one obtained across the capacitor C_2, which means the feedback signal is out-of-phase with the voltage at the transistor by 180^o. This is due to the fact that the voltages developed across the capacitors C_1 and C_2 are opposite in polarity as the point where they join is grounded. Further, this signal is provided with an additional phase-shift of 180^o by the transistor which results in a net phase-shift of 360^o around the loop, satisfying the phase-shift criterion of Barkhausen principle.

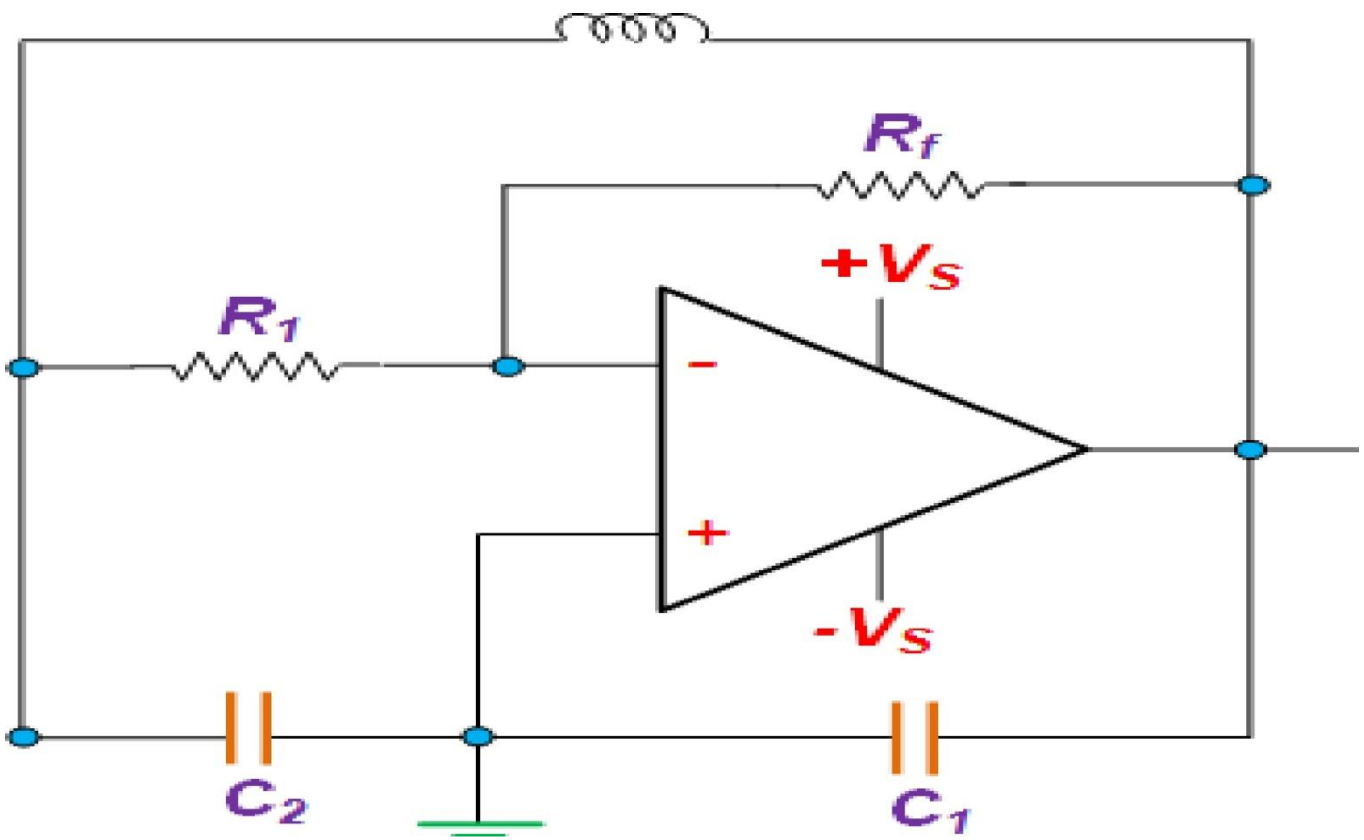
At this state, the circuit can effectively act as an oscillator producing sustained oscillations by carefully monitoring the **feedback ratio given by (C_1 / C_2).** The frequency of such a **Colpitts Oscillator** depends on the components in its tank circuit and is given by

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

Where, the C_{eff} is the effective capacitance of the capacitors expressed as

$$\frac{C_1 C_2}{C_1 + C_2}$$

As a result, these oscillators can be tuned either by varying their inductance or the capacitance. However the variation of L does not yield a smooth variation. Hence they are usually tuned by varying the capacitances which are generally ganged, due to which a change in any one of them changes both of them. Nevertheless, the process is tedious and requires special large-valued capacitor. Thus, the Colpitts oscillators are seldom preferred in the applications where in the frequency varies but are more popular as fixed frequency oscillators due to their simple design. Further they offer better stability in comparison with the Hartley Oscillators as they are exempted from the mutual inductance effect present in-between the two inductors of the latter case.



Fipure 2 Colp itts Oscillator Usinp an p-Amp

Apart from the BJT-based Colpitts Oscillator shown, they are also realizable using valves or FET (Field Effect Transistor) or Op-Amp. Figure 2 shows such a **Colpitts oscillator** which uses an Op-Amp in inverting configuration in its amplifier section while the tank circuit remains similar to that in the case of Figure 1. This kind of circuit functions almost analogous to that of the one explained earlier. However, here the gain of the oscillator can be adjusted individually just by using the feedback resistor R_f, as the gain of the inverting amplifier is given as $-R_f / R_1$. From this, it can be noted that, in this case, the gain of the circuit is less dependent on the circuit elements of the tank circuit.

Typically, the operating frequency of the **Colpitts oscillators** ranges from 20 KHz to 300 MHz. However they can even be used for microwave applications as their capacitors provide low reactance path for the high-frequency signals. This results in better frequency stability as well as a better sinusoidal output waveform. Moreover, they are also extensively used as surface acoustical wave (SAW) resonators, sensors and in mobile and communication systems.

Clapp Oscillator:

Clapp oscillator is a variation of Colpitts oscillator in which an additional capacitor (C_3) is added into the tank circuit to be in series with the inductor in it, as shown by Figure 1.

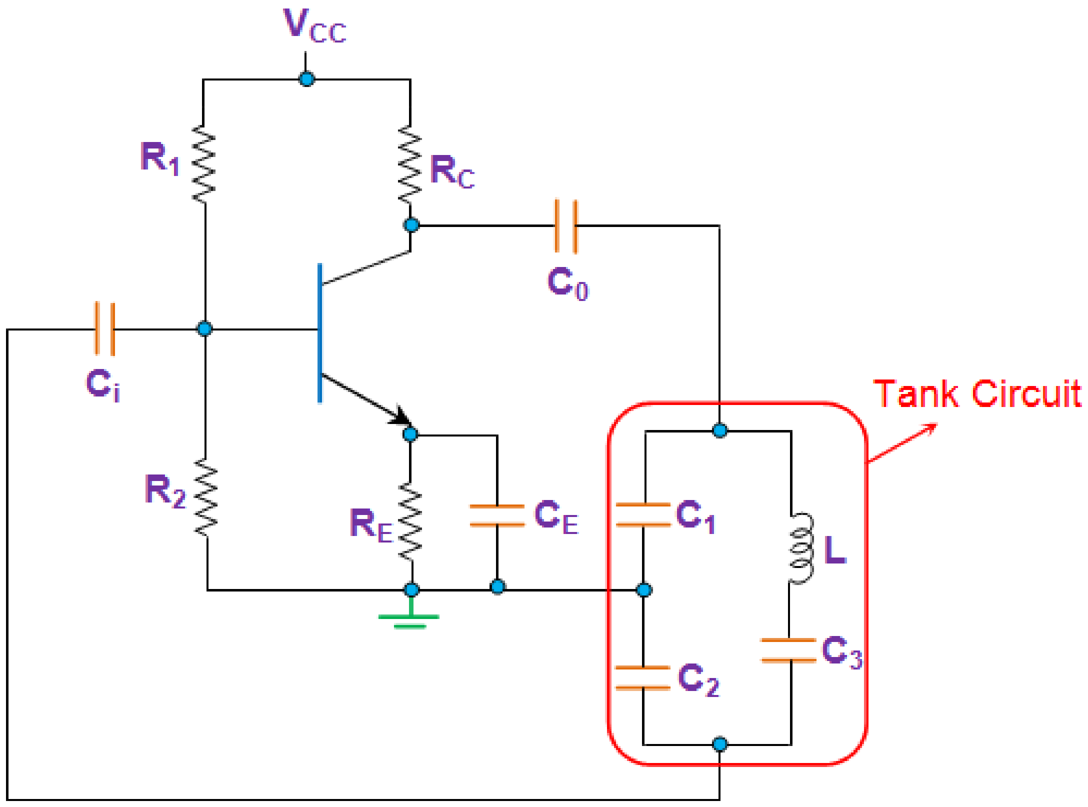


Figure 1 Clapp Oscillator

Apart from the presence of an extra capacitor, all other components and their connections remain similar to that in the case of Colpitts oscillator.

Hence, the working of this circuit is almost identical to that of the Colpitts, where the feedback ratio governs the generation and sustainability of the oscillations. However the frequency of oscillation in the case of **Clapp oscillator** is givenby

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

Usually the value of C_3 is chosen to be much smaller than the other two capacitors. This is because, at higher frequencies, smaller the C_3, larger will be the inductor, which eases the implementation as well as reduces the influence of stray inductance. Nevertheless, the value of C_3 is to be chosen with utmost care. This is because, if it is chosen to be very small, then the oscillations will not be generated as the L-C branch will fail to have a net inductive reactance. However, here it is to be noted that when C_3 is chosen to be smaller in comparison with C_1 and C_2, the net capacitance governing the circuit will be more dependent on it.

Thus the equation for the frequency can be approximated as

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

Further, the presence of this extra capacitance will make the **Clapp oscillator** preferable over Colpitts when there is a need to vary the frequency as is the case with **Variable Frequency Oscillator** (VCO). The reason behind this can be explained as follows.

In the case of Colpitts oscillator, the capacitors C_1 and C_2 need to be varied inorder to vary its frequency of operation. However during this process, even the feedback ratio of the oscillator changes which inturn affects its output waveform. One solution to this problem is to make both C_1 and C_2 to be fixed in nature while achieve the variation in frequency using a separate variable capacitor. As could be guessed, this is what the C_3 does in the case of **Clapp oscillator**, which inturn makes it more stable over Colpitts interms of frequency. The frequency stability of the circuit can be even more increased by enclosing the entire circuit in a chamber with constant temperature and by using a Zener diode to ensure constant supply voltage.

In addition, it is to be noted that the values of the capacitors C_1 and C_2 are prone to the effect of stray capacitances unlike that of C_3. This means that the resonant frequency of the circuit would be affected by the stray capacitances if one had a circuit with just C_1 and C_2, as in the case of Colpitts oscillator. However if there is C_3 in the circuit, then the changes in the values of C_1 and C_2 would not vary the resonant frequency much, as the dominant term would then be C_3.

Next, it is seen that the **Clapp oscillators** are comparatively compact as they employ a relatively small capacitor to tune the oscillator over a wide frequency band. This is because, here, even a slight change in the value of the capacitance varies the frequency of the circuit upto a great extent. Further they exhibit high Q-factor with a high L/C ratio and lesser circulating current in comparison with Colpitts oscillators. Lastly it is to be noted that these oscillators are highly reliable and are hence preferred inspite of having a limited range of frequency of operation.

Crystal Oscillators:

Crystal Oscillators can be designed by connecting the crystal into the circuit such that it offers low impedance when operated in series-resonant mode (Figure 2a) and high impedance when operated in anti-resonant or parallel resonant mode (Figure 2b).

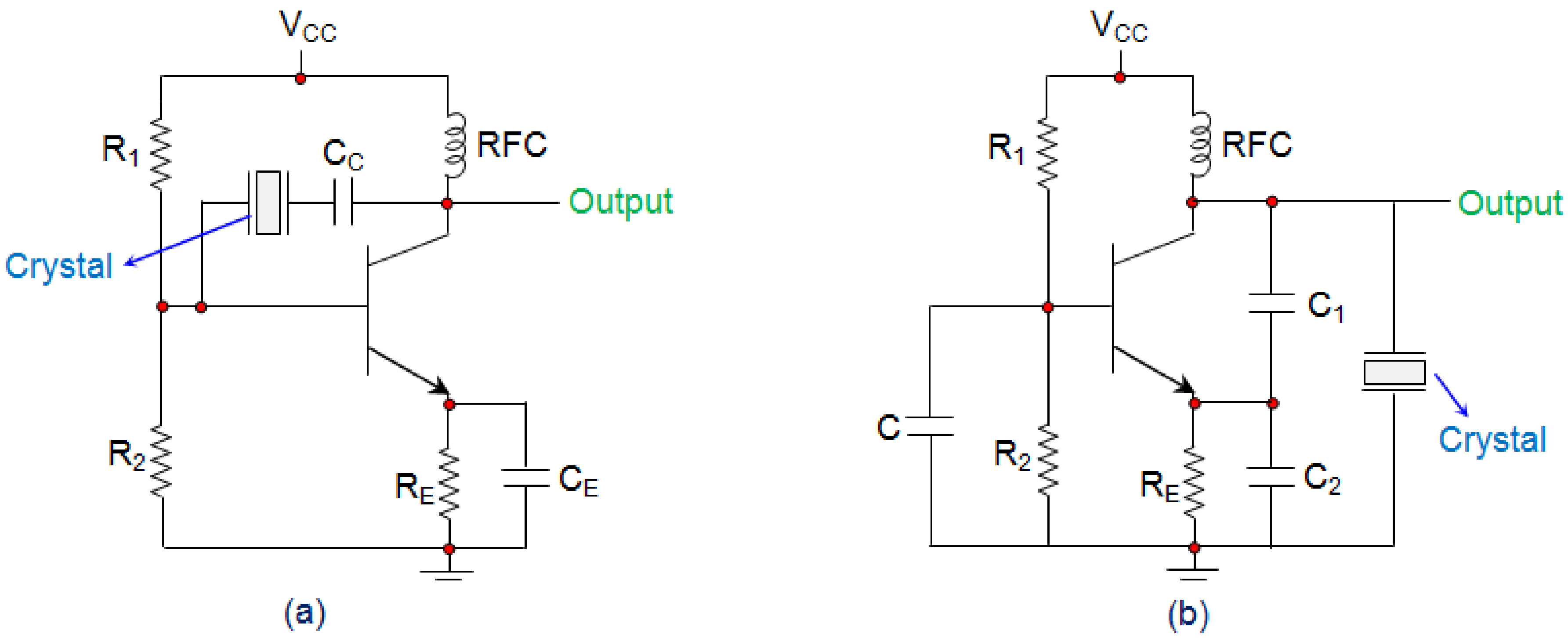


Figure 2 Crystal Oscillator Operating in (a) Series Resonance (b) Parallel Resonance

In the circuits shown, the resistors R_1 and R_2 form the voltage divider network while the emitter resistor R_E stabilizes the circuit. Further, C_E (Figure 2a) acts as an AC bypass capacitor while the coupling capacitor C_C (Figure 2a) is used to block DC signal propagation between the collector and the base terminals. Next, the capacitors C_1 and C_2 form the capacitive voltage divider network in the case of Figure 2b. In addition, there is also a Radio Frequency Coil (RFC) in the circuits (both in Figure 2a and 2b) which offers dual advantage as it provides even the DC bias as well as frees the circuit-output from being affected by the AC signal on the power lines.

On supplying the power to the oscillator, the amplitude of the oscillations in the circuit increases until a point is reached wherein the nonlinearities in the amplifier reduce the loop gain to unity. Next, on reaching the steady-state, the crystal in the feedback loop highly influences the frequency of the operating circuit. Further, here, the frequency will self-adjust so as to facilitate the crystal to present a reactance to the circuit such that the Barkhausen phase requirement is fulfilled.

In general, the frequency of the crystal oscillators will be fixed to be the crystal's fundamental or characteristic frequency which will be decided by the physical size and shape of the crystal. However, if the crystal is non-parallel or of non-uniform thickness, then it might resonate at multiple frequencies, resulting in harmonics. Further, the crystal oscillators can be tuned to either even or odd harmonic of the fundamental frequency, which are called Harmonic and Overtone Oscillators, respectively. An example for this is the case where the parallel resonance frequency of the crystal is decreased or increased by adding a capacitor or an inductor across the crystal, respectively.

The typical operating range of the crystal oscillators is from **40 KHz to 100 MHz** wherein the low frequency oscillators are designed using OpAmps while the high frequency-ones are designed using the transistors (BJTs or FETs). **The frequency of oscillations generated by the circuit is decided by the series resonant frequency of the crystal and will be unaffected by the variations in supply voltage, transistor parameters, etc. As a result, crystal oscillators exhibit high Q-factor with excellent frequency stability, making them most suitable for high-frequency applications.** However care should be taken so as to drive the crystal with optimum power only. This is because, if too much of power is delivered to the crystal, then the parasitic resonances might be excited in the crystal which leads to unstable resonant frequency. Further even its output waveform might be distorted due to the degradation in its phase noise performance. Moreover it can even result in the destruction of the device (crystal) due to overheat.

Applications:

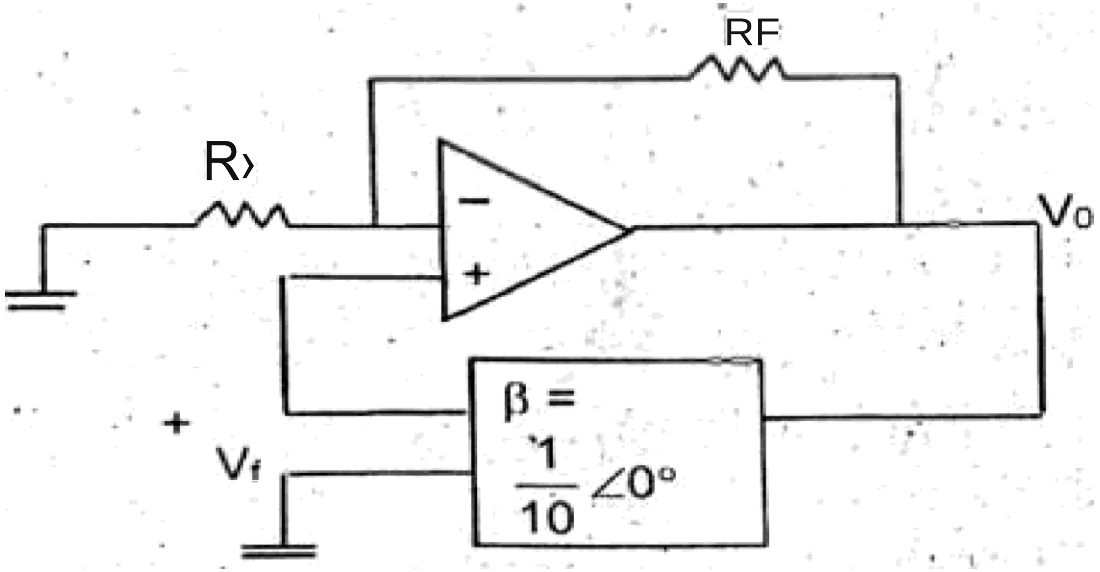
Crystal oscillators are compact in size and are of low cost due to which they are extensively used in electronic warfare systems, communication systems, guidance systems, microprocessors, microcontrollers, space tracking systems, measuring instruments, medical devices, computers, digital systems, instrumentation, phase locked loop systems, modems, sensors, disk drives, marine systems, telecommunications, engine controlling systems, clocks, Global Positioning Systems (GPS), cable television systems, video cameras, toys, video games, radio systems, cellular phones, timers, etc.

GATE Questions with Solutions

Relation between R, and RF 'for

sustained Oscillations if g = $\frac{1}{}$ xYO°

for the following circuit?



{A) RF ^ 4R 1 QB) RF = 10R‹

(C) RF = 2R 1 {D) RF 9R 1

gtj, ,q $1+\frac{R_F}{R_1}$

$A_g = 1$

$$\Rightarrow \left[1+\frac{R_F}{R_1}\right]$$

,1 10D

iv

" 1" 0•

+ ’*F

\O

R1

RF 9R1

Choice (D)

A colpltts oscillator has a coil with sn inductsncs of 50 yH and is tuned by a capacitor 400 pF across ampljf‹er input & 200 pF across the output. Then the frequency of oscillation & thé minimum gain for maintaining oscillations?

(A) 1,95 MHz, 3 (B) 1.95 MHz, 2

(C) 2.9 MHz, 2 (O) 2.9 MHz, 2

IOl. /Or colpitts OSCIllatOf

$f_0 = \frac{1}{2.L}$, C_e ' $\frac{C_1C_2}{C_1 + C;}$

C_{eq} $\frac{400 \times 20}{600}$ 133.3Z pF

)0 $\frac{1}{2xg50 \times 133.33x1O"^{18}}$

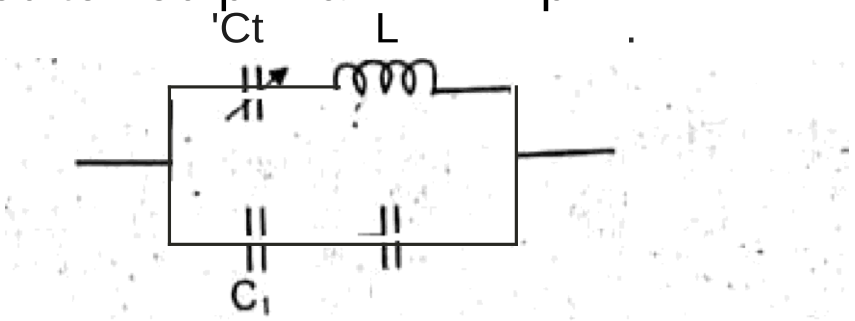
1.95,MHz

For maintaining oscillations. A§ 1

$A_{loop} = A_{v0}. \frac{2}{C_1} = 1$

A_{v0} $\frac{C;}{Ct}$ $\frac{400}{200} = 2$ Choice (B)

7.10. A c1app oscillatof has the following circuit components C› ' 5 00 pF Cz 500 pF /- = 50 yH and Ca is d 50 to 250 pF variable Ca p» ! Or



Find out the tuj3ing frequency range?

{A) 1.98 to 10.34 MHZ

(B) 2.34 to 11,56 MHz.

(C) 3.35 to 12.5 MHZ

(D) 5.34 to 15.4 MHz

Sol. $f_a = \frac{1}{2\sqrt{LC_{eq}}}$ $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1y}{} \frac{1}{C_3}$

$ct = \frac{SOOO x 500 x 50}{SOOO x 500 + 50OD x 5D + 500 x 50}$

= 4¿.045 pF for C› = 60 pF

$t = \frac{1}{2\pi\sqrt{50 x 45.045 x10''^{1'}}}$

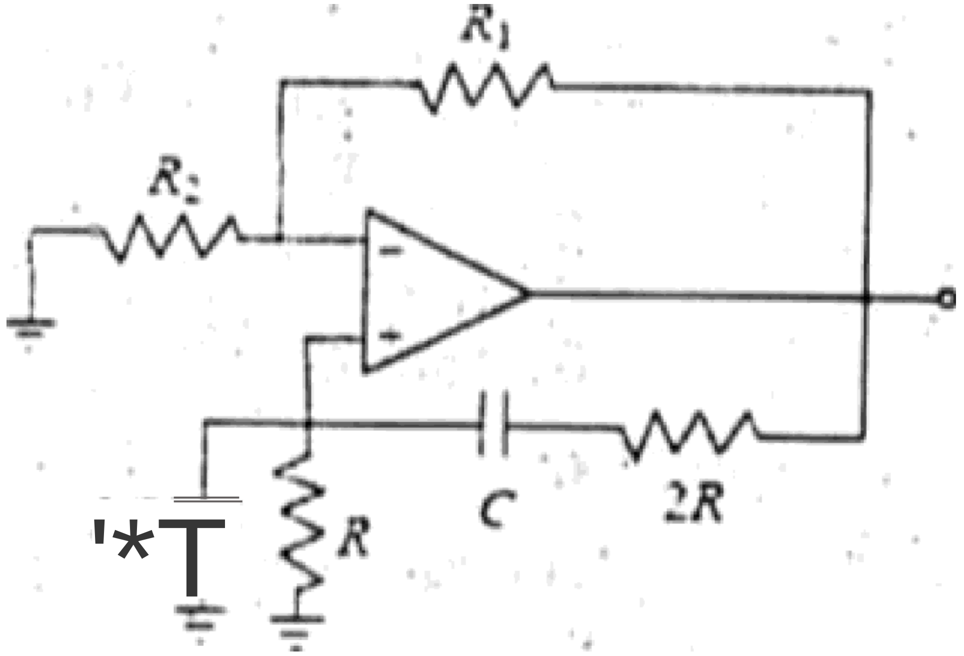
= 3.35 MHz

C»q= 161,29 pF Dr C› = 250 pF

Then to= 12.5 MHz Choice (C)

C ° I ° a 6 • a

1•11• The circuit shown in the figure has an ideal opamp. The oscillakon frequency and the condition to "'sustain the oscillañon8, a spectively are



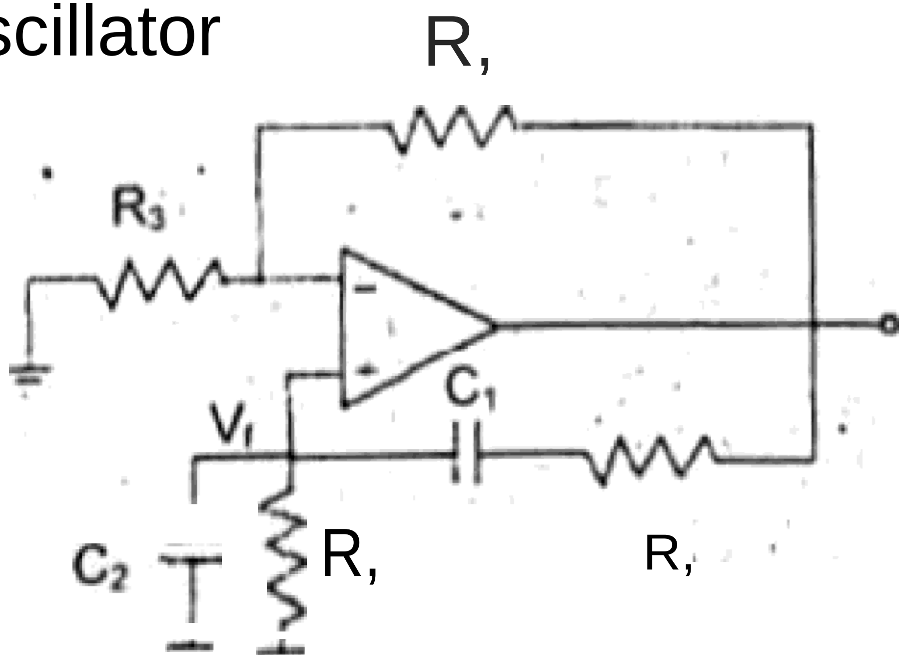
(A) $\frac{1}{CR}$ and H, - e,

$\overline{}$ ce ’°‘ = 4Rz

$\frac{1}{2CR}$ and H, - H,

$\frac{1}{}$ and R› =,4R2

Sol. The given circuit is weiri brigge Oscillator



The gain of the op–amp Is

A 1 ^ $\frac{R_f}{R_g}$ and feedback fagtor

Lat Z1 · R› <- 1/sGa an<f Zz = /+• || 1/sCa

By substituting all values, ww get finally

$$B = \frac{j\omega R}{1 + j\omega(R_1C_1 + R_2C_2 + R_2C_1) - \omega_2 R_1R_2C_1C_2}$$

But B is real quantity so equate

1 — cu*o R› R eC ›C a -"0

Thus thd oscillation,

$$\omega_0 = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

"

From the given data

R1 ^ 2R, R¿ = R

C› = C. C2 = 2C , “ ." $\frac{1}{2RC}$

And B - R 2C 1

1 1 ^ R 2Cp + R yC 1

Sub all values

B - $\frac{RG}{2RG + £RG + RG}$ $\frac{1}{5}$

For sustaine<t oscillation AP ☐ = 1

$A = \frac{1}{0} \therefore 1 + \frac{R_f}{Rq} = 5$

But R› - R1 and Ra = Rx

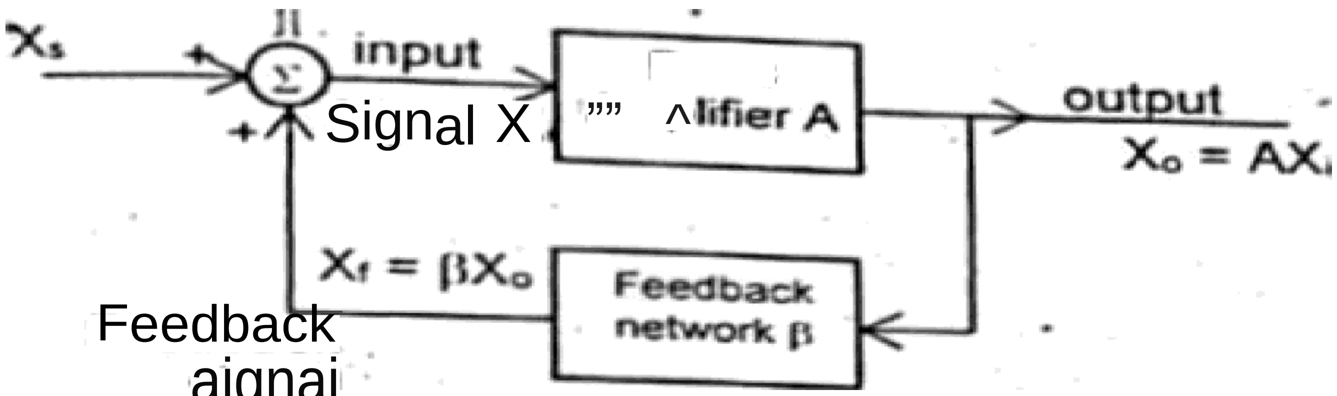
•.Rt = 4R»

GhOlGR (☐)

7.12. Show 4at a feedback ampli! er ssn be made to wo6 as an osciliator

(ESE

* O • > e f3e *»!ized positim feedback ampiifier circuit blo6 diaga jyj iS shown below:



we know that X; = p, + jg,

= —

X_o AX_{in}

X» A {Xs + Xr)

=

X_o $AX_s + A\beta X_o$

to = f App Ax,

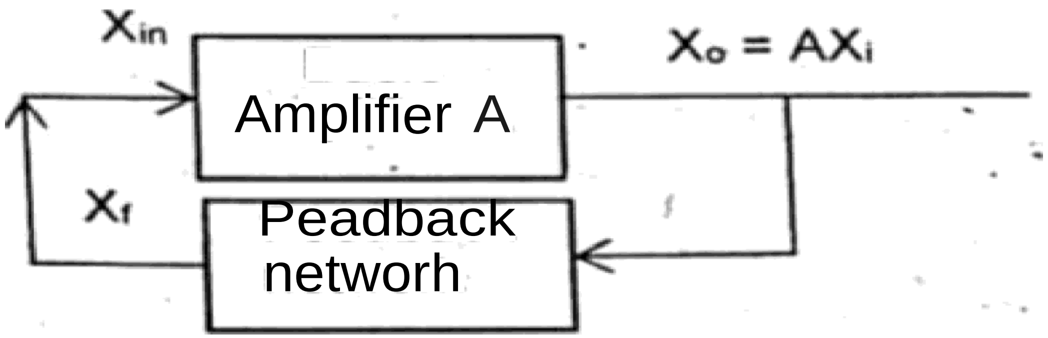
□›verall gain with positive feeclaacx

⇒ Al = — ———

If Ag 1 ⇒ jA/ —+ w

”inFinita gain msans, with no !nput 'ñre can expect some outpug in fact in oscillator there is no lnput slgnal, it works on añher noise signal the circuit ¥ansienD.

Oscillator:-



A§ = 1

.-. w necewary condition fzr osėllator

circuits aho kno¿n to . be one •*

Bachanmn criteñon.

N RSR@ condTtiOfiS far osollaton

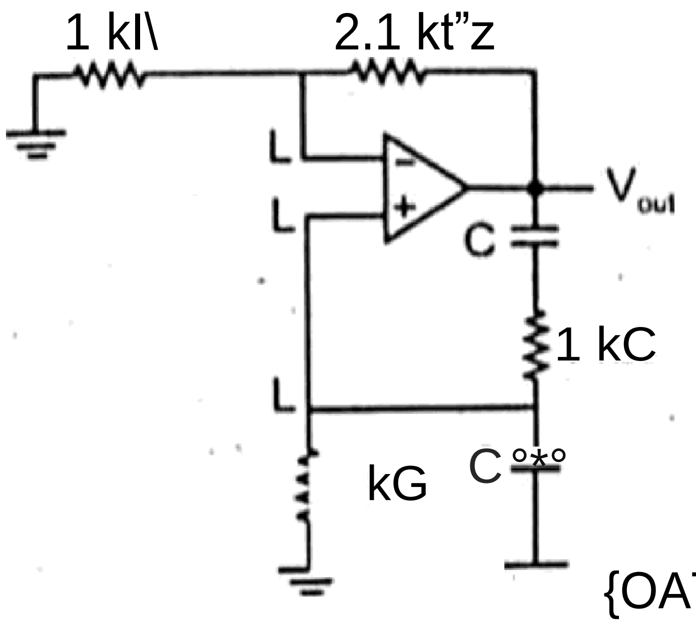
(Or) BaAh€tnm n cn e nO$3 if 0 fi)l8tOM

(i) magnitude of loop gain should be equal to 1 i.e.)Ap) = 1

(ii) Loop angD should be made to 0• (or) 36d•. i.e ZAg =0• or 360•.

Hence, a feedback AmplTier (positive f back) can be made to work as an oscillator by following the above two condiñons.

3. The value of C required for sinusoidal o»cIllatIona of frequency 1 KHz In the circuit of fig. is



{OATE 200¥)

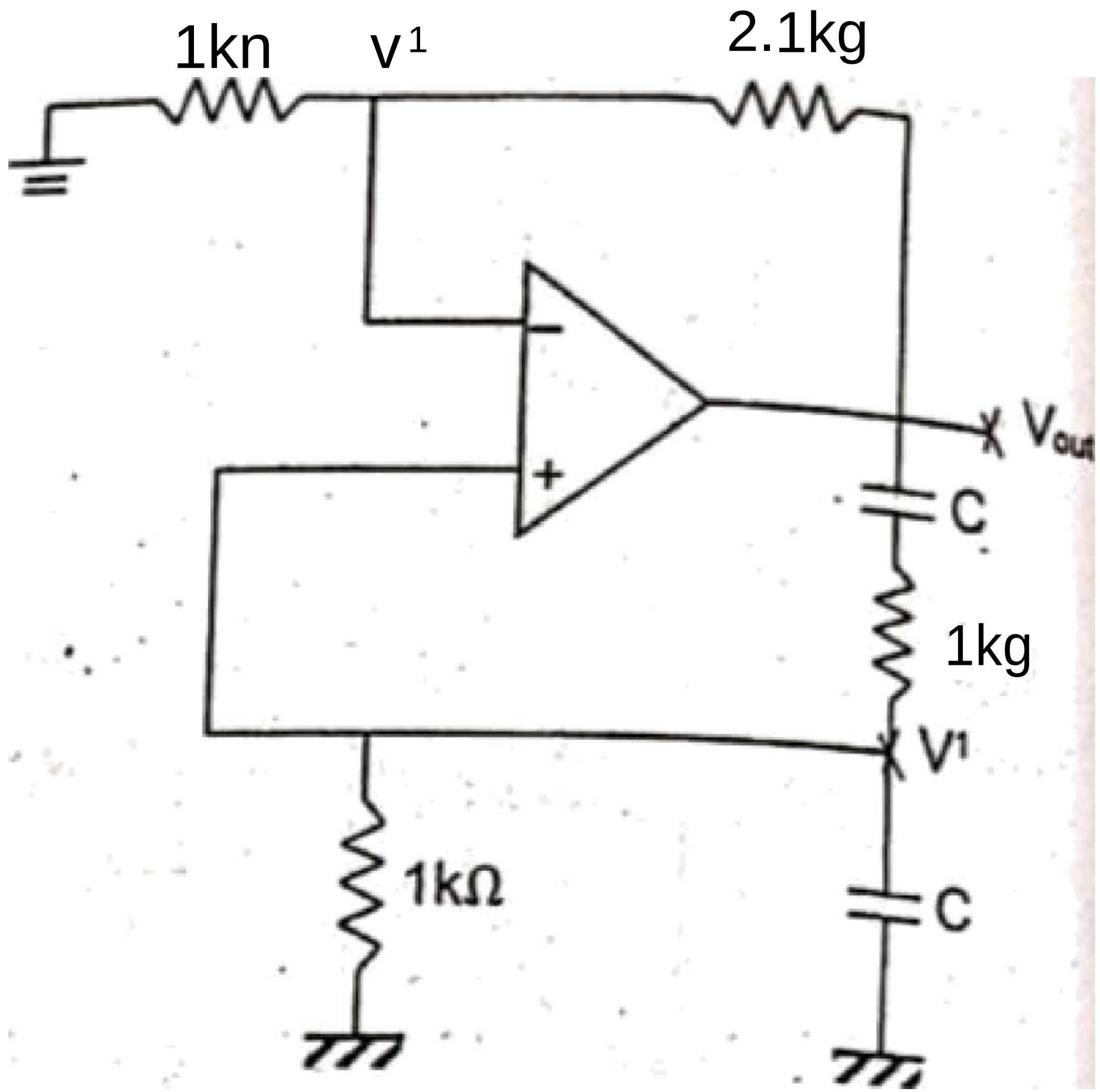
(A) $\frac{1}{2\pi}$ µF

(B) 2x /‹F

(C) t—q, F

(D) z•/srr

3.



—> apply XCL at V^1

$$\frac{V^1}{X_C} + \frac{V^1}{R} + \frac{V^1 - V_{out}}{X_C + R} = 0$$

:=Z V’ 1 [1/Xc + 1/R + 1/(¥j; +R’) "*ou\ / (Xg +R)

*ovt / v’ _6 ”R,p ***C / RX¿ =1+ * **** / RXg

=1+ ** Xq +2 / RXc =3+ R+ / Xc **C / R

For O #4iañOns Ima§inay pa3isegualB

ze¿o

$$\frac{R}{X_C}+\frac{X_C}{R}=0$$

n joGR ecn't

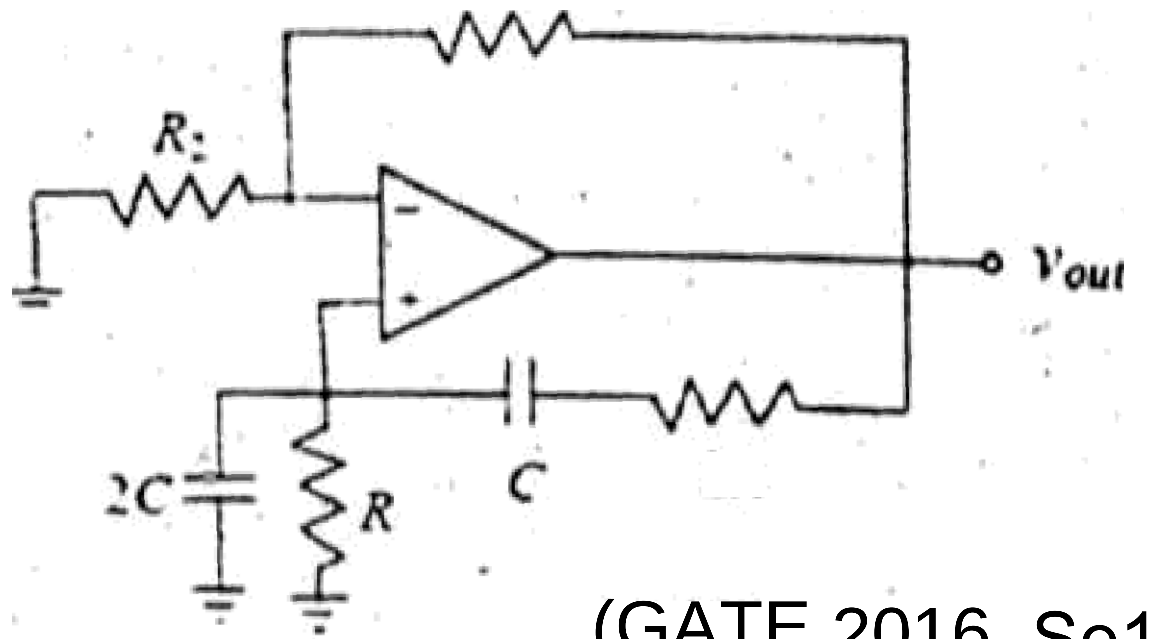
25 =>\¿ =—.-/

p2p2

$$\Rightarrow C=\frac{1}{R\omega}=\frac{1}{10^3\times2\pi\times10^3}=\frac{1}{2\pi}\mu F$$

Choice (*)

20. The circuit shown in the figure has an ideal opamp. The oscillation frequency and the condition to sustain the oscillation » respectively are



(GATE 2016, Se1•1\

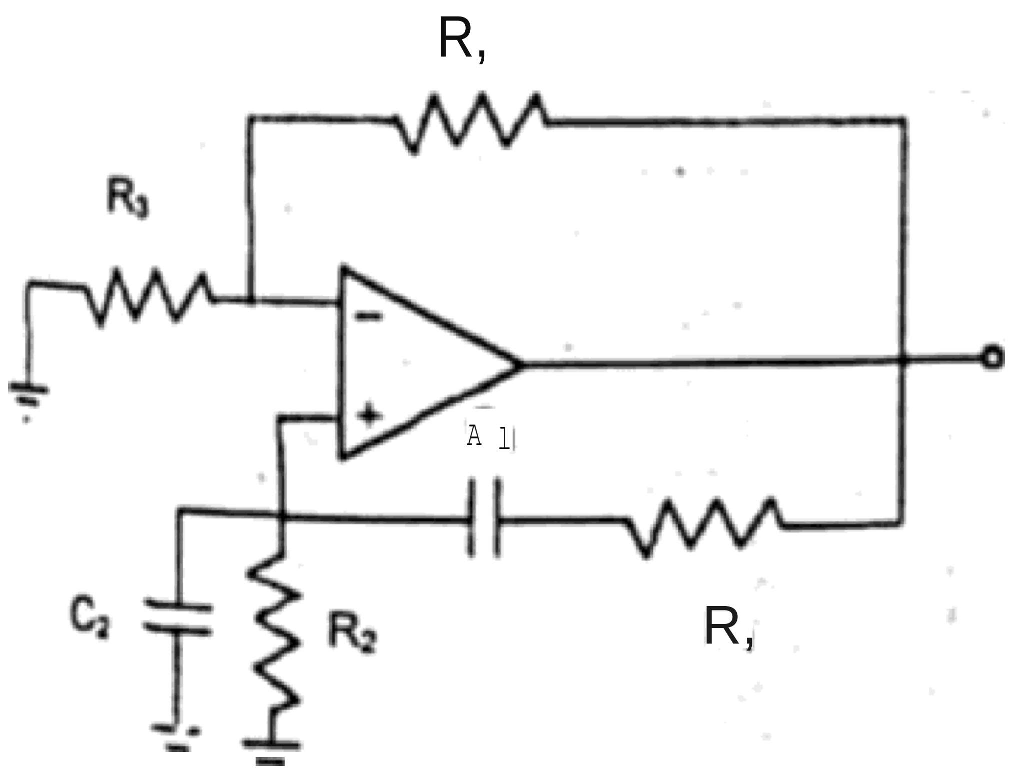
(A) $\frac{1}{CR}$ and $R_1 = R_2$

(B) $\frac{1}{CR}$ and $R_1 = 4R_2$

(C) $\frac{1}{2CR}$ and $R_1 = R_2$

(D) $\frac{1}{2CR}$ and $R_1 = 4R_2$

tA. The given circuit is wein bridge Oscillator



rhe gain of the opa mp is

$$A = 1 + \frac{R_f}{R_3}$$ and feed back factor

$$B = \frac{V_f}{}$$

‘ e’ *› * Ri + 1/SCt

^’ d Hz = R› 1/SCz

$$V_f = \frac{Z_2 \times V_0}{Z_1 + Z_2}$$

$$= \frac{}{1 \text{"'} \quad 2}$$

Sub all •»iuas mB we gat finally

$$B = \frac{j\omega R_2 C_1}{1 \quad j\omega(R_1C_1 + R_2 C_2 + R_2C_1) - \omega_2 R_1 R_2 C_1 C_2}$$

BUt B is real quantity ao equate

1 - ‹» RiR›C›C a = 0

Thus the frequency of oscillation,

$$f›g = \frac{1}{R t CtC j}$$

$$= \frac{1}{}$$

From the given data

R‹ =2R,

Rz = R

C› = C,

Cz - 2C

And $B = \dfrac{R_2C_1}{R_1C_1 + R_2C_2 + R_2C_1}$

Sub all values

$B = \dfrac{RC}{2RC + 2RC + RC} = \dfrac{1}{5}$

For sus&lned oscillañon AB= 1

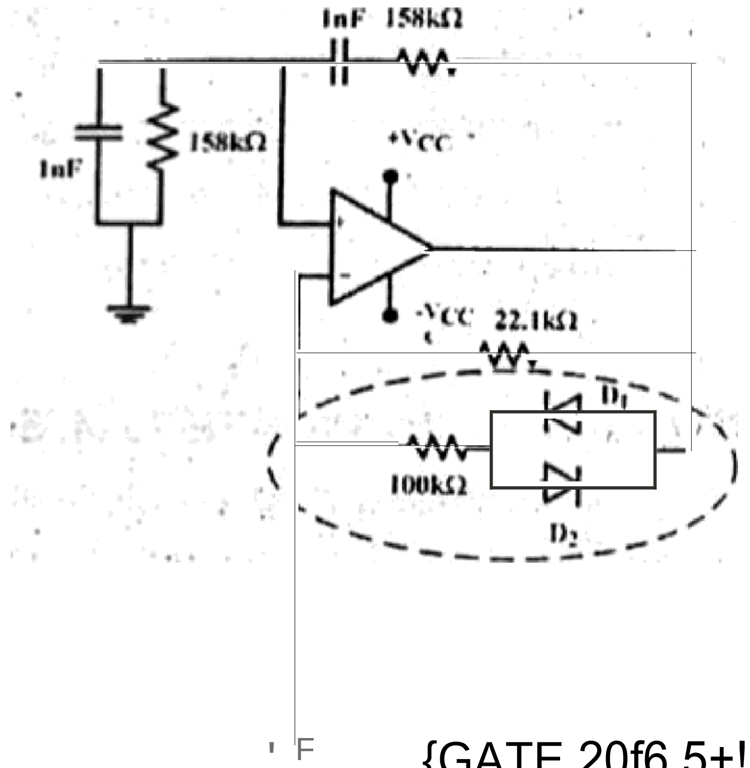
$A = \dfrac{1}{B}$.•.$1 + \dfrac{R_f}{R_y} = 5$

But Ri - R› and Ra - Rz

.'.Rs = 4Rz

Choioe (D)

22. Consider .the oscillator circuit shown in the figure. The function of the net«gtt (shoem in do¥ed IinRs) consisting o/ ;yg 100krt resistor in series with the \gp diodes connected back to back is \g



{GATE 20f6,5+!•!)

(A) Integ...

(4) !f1!*OdU«e A mplitude stabilizdti0l1 bf preventing the op amp from satufa!*A "and thus " Producing sl«**0l**! OS$ llatioFl Of €xed amplitud

(B) introduce amplitude stabilizatl 0* ** forcing the opamp to swing betñ**' p OS tive a f1d negative satura ti0* and thus producing spuare *** O6Ctt a Of fixe d a mplitude

(C) introduce freq * ncy stabiliZ$tl** fgrcing the circuit to oscilla!* *' S) // e) l q ue nc y

(D) e Fla ble the !«p gains tO td*e on a value th»t produces sqgare wave °cillalions

22. The given circuit is a wein bridge oscillator, it produces sinusoidal oscillations. The back – to – back diodes introduces amplitude stabilization by preventing the op-amp from saturation.

Choice (A)