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RC OSCILLATORS

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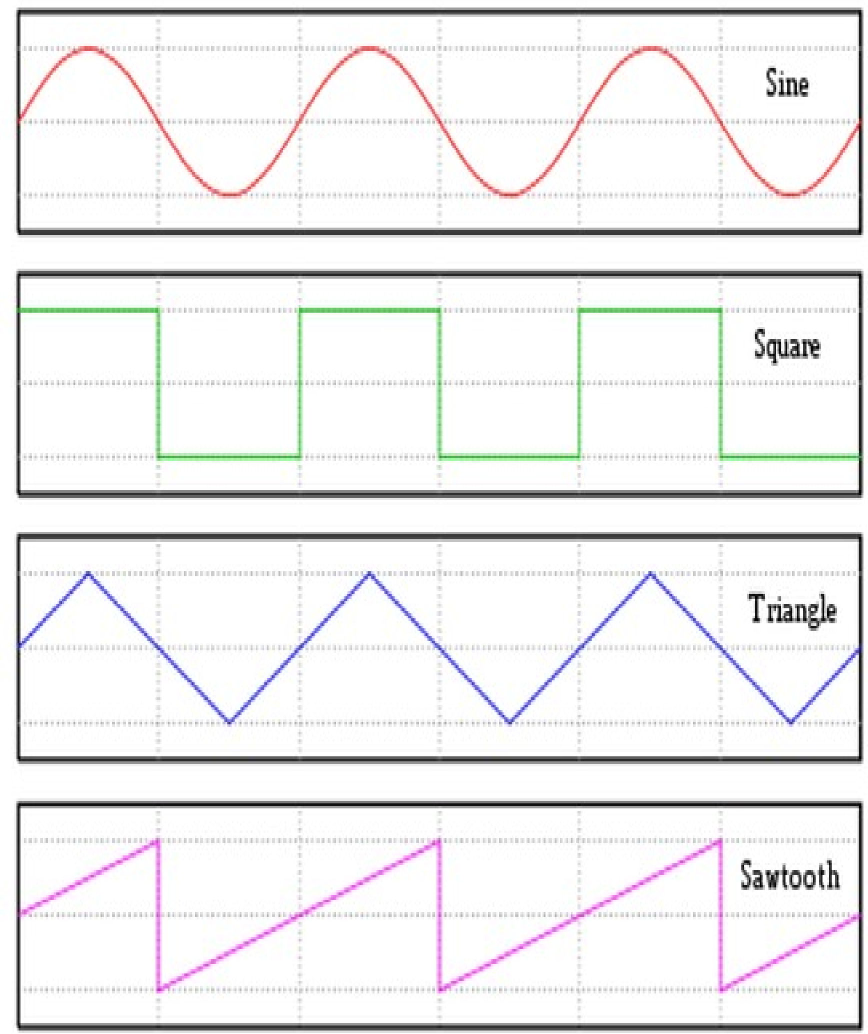
Oscillator

An Oscillator is an electronic circuit that produces a periodic, oscillating electrical signal, which could be a sine wave or a square wave or of some other waveform. An Oscillator converts direct current (DC) from a power supply to an alternating current (AC) signal.



Sine wave oscillator

- A Sine wave oscillator gives a sine wave output. Sine wave oscillators are based on Feedback.
- The oscillator circuit has two parts: (1) An amplifier whose gain is A. and (2) A feedback network whose attenuation is β.
- The attenuation of the feedback network, β is frequency dependent.
- The feedback network also introduces a phase change in the signal.

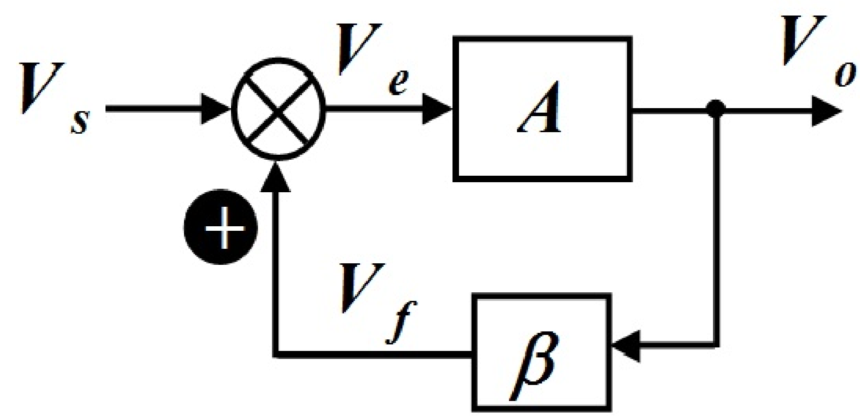
Positive Feedback

- Feedback is a process in which the output signal from an amplifier is sampled and fed back to the amplifier together with its input after modification by an attenuating network.
- In Positive feedback the input and the feedback signal are in phase.
- An important use of positive feedback is for producing oscillations.

A Feedback Network

A schematic diagram of a Feedback system is shown in the figure.

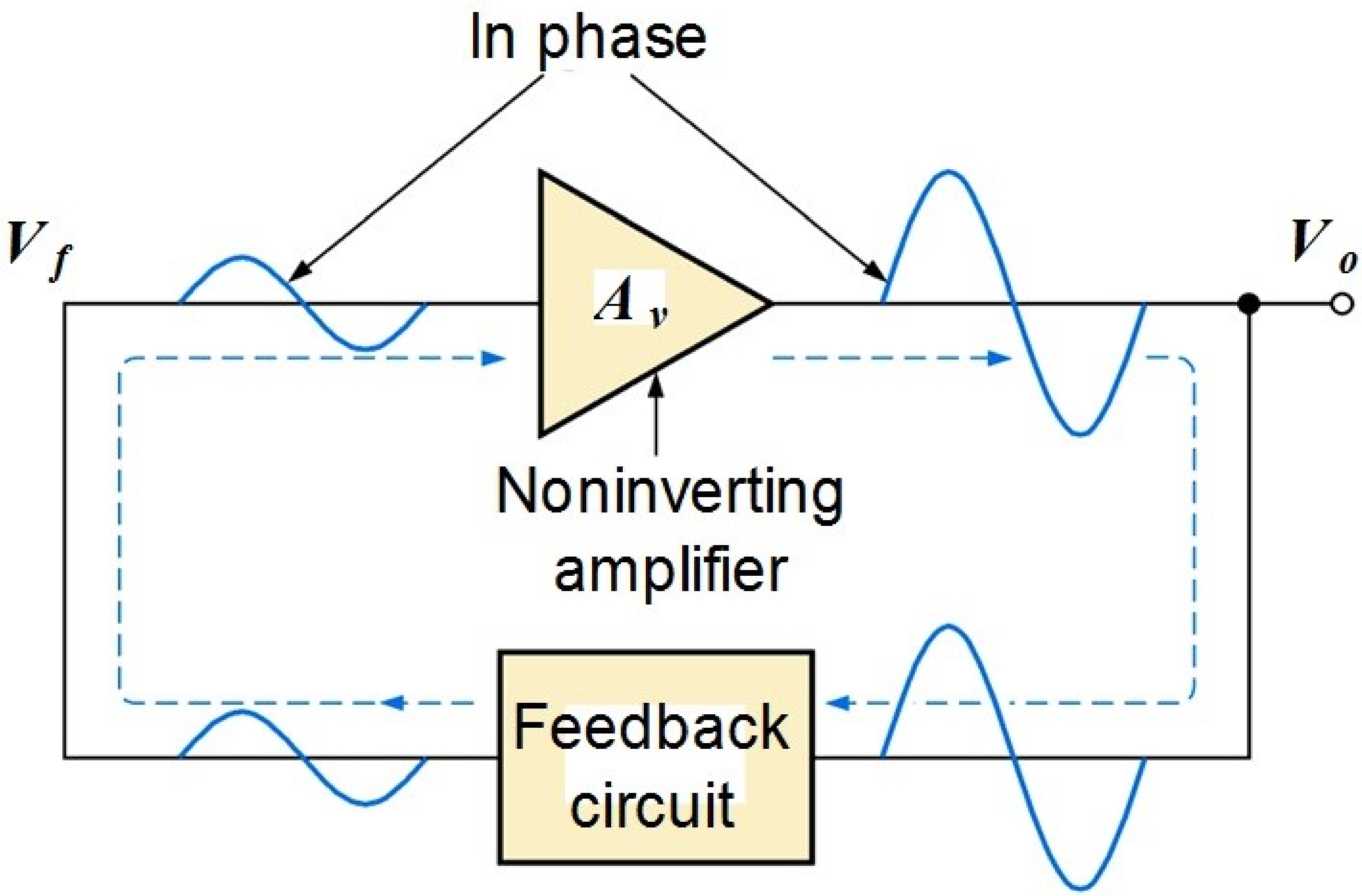
- V_s is the input signal voltage
- V_e is the input to the amplifier
- V_o is the output of the amplifier



•***A*** is the gain of the amplifier.

•β is the attenuation produced by the feedback network.

•In general ***A*** as well as β are complex. They change the amplitude and also the phase of the signal.


In phase
V_f
A_v
V_o
Noninverting amplifier
Feedback circuit

Barkhausen Criterion

- Barkhausen Criterion gives the condition under which a feedback network acts as an oscillator.
- There are two conditions:

1. The total phase change in the signal while going through the feedback loop is 0 (or $2n\pi$)
2. The net gain of the signal while going through the feedback loop is $A\beta = 1$

- In short, Loop Gain is $A\beta = 1 + j\,0$.

Meaning of Barkhausen's First Criterion

Barkhausen's first criterion is that the total phase change in the signal while going through the feedback loop should be 0 (or $2n\pi$).

What happens for signals whose total phase change while going through the feedback loop is not 0 ? At any given time a large number of signals superpose, each with a slightly different phase. At any time half of all the signals will be positive and half negative. And they add up to zero.

But if the signals are exactly in phase then they just add up and produce a resultant amplitude that is much larger than the amplitude of the original input signal.

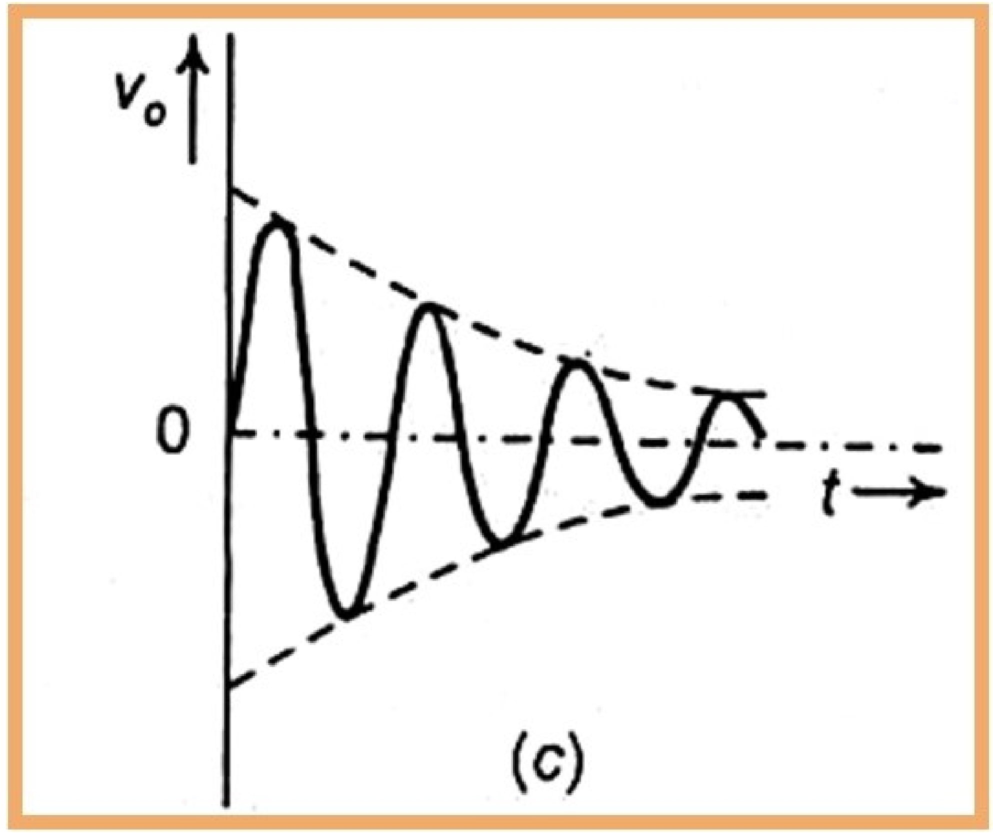
Barkhausen's First Criterion helps us to identify the Frequency at which the Feedback circuit will oscillate.

Meaning of Barkhausen's Second Criterion

Barkhausen's Second criterion is that the total amplification change in the signal while going through the feedback loop should be 1. That is, $A\beta = 1$.

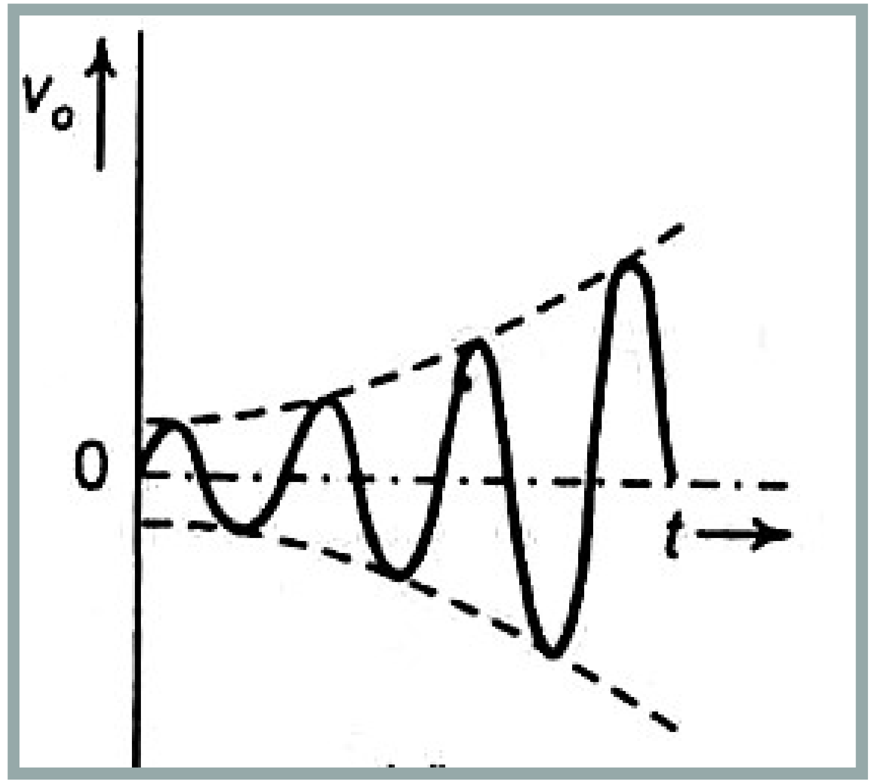
What happens if Aβ < 1 for a given frequency?

If Aβ < 1 then the signal amplitude at the given frequency will get smaller and smaller and ultimately die down.



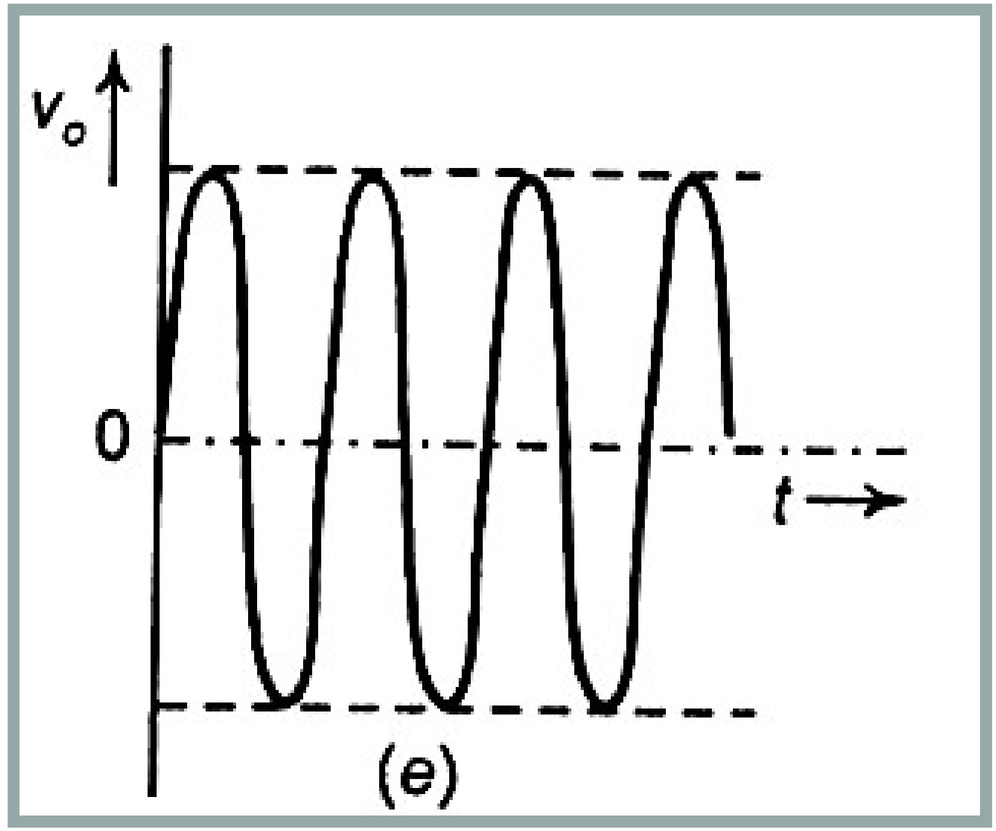
What happens if Aβ > 1 for a given frequency?

If Aβ > 1 then the signal amplitude at the given frequency will grow indefinitely. This condition is not sustainable. In practice the growth of the signal is checked due to some limiting mechanism in the circuit.



What happens if Aβ = 1 for a given frequency?

If Aβ = 1 then we get sustained oscillations. The circuit supplies its own input signal and the oscillation continues at constant amplitude.



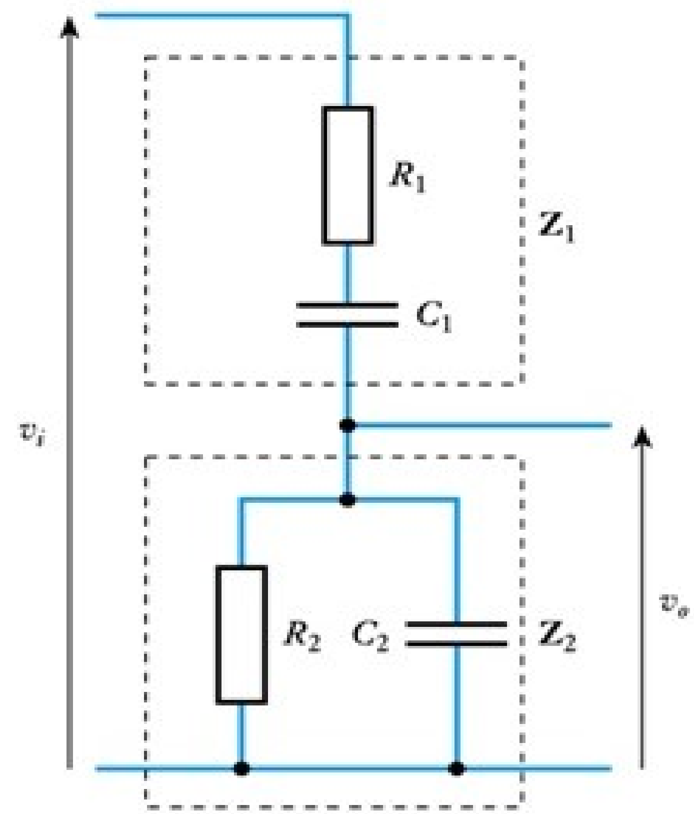
Why do we keep Aβ slightly > 1 in practical oscillators?

If Aβ > 1 then we get oscillations that grow in amplitude. The circuit supplies its own input signal and the oscillation continues with increasing amplitude.

In practical oscillators, we keep Aβ slightly > 1. This helps in converting thermal noise into sustained oscillation in the beginning. Later on, some other nonlinear factor like limiting feature of supply voltage, or negative resistance device is used to make the effective value of Aβ equal to 1 at desired amplitude and stabilize the oscillation.

Wien Bridge Oscillator

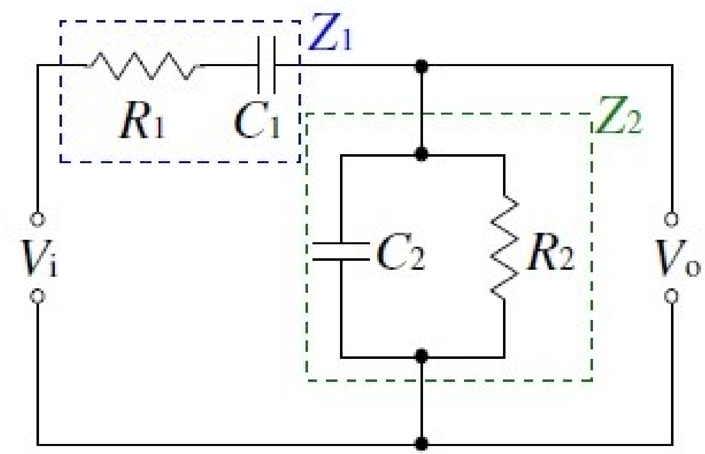
- A Wien Bridge oscillator consists of an amplifier and a feedback network.
- It uses a Wien Bridge for its Feedback network.
- The Wien Bridge consists of a series RC combination and a parallel RC combination as shown in the figure.
- This bridge is used to provide positive feedback to a non-inverting amplifier.



A Wien Bridge

Condition for Oscillation

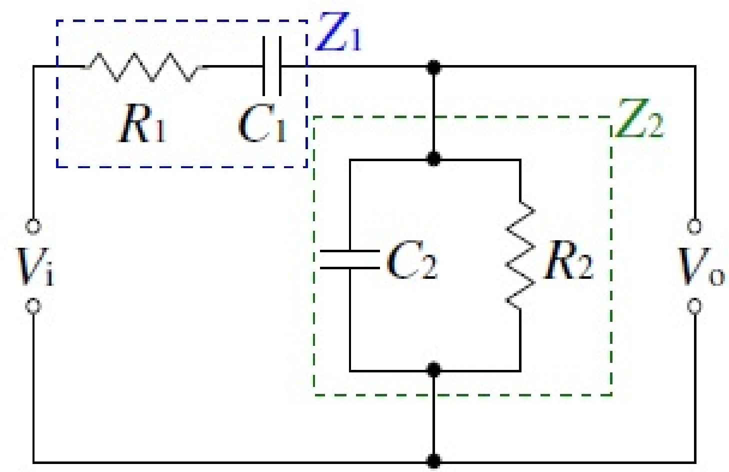
- The Figure shows a Wien Bridge. It consists of a lead-lag circuit where R_1C_1 form the time lag portion and R_2C_2 form the lead portion. The feedback network consisting of this Wien bridge provides 0^o phase shift.



$$Let\ X_{C1}=\frac{1}{\omega C_1},\ X_{C2}=\frac{1}{\omega C_2}$$

$$Z_1=R_1-jX_{C1}$$

$$Z_2=\left[\frac{1}{R_2}+\frac{1}{-jX_{C2}}\right]^{-1}=\frac{-jR_2X_{C2}}{R_2-jX_{C2}}$$



Therefore the Feedback factor β is

$$\beta=\frac{V_o}{V_i}=\frac{Z_2}{Z_1+Z_2}=\frac{-jR_2X_{C2}/(R_2-jX_{C2})}{(R_1-jX_{C1})+-jR_2X_{C2}/(R_2-jX_{C2})}$$

$$\beta=\frac{-jR_2X_{C2}}{(R_1-jX_{C1})(R_2-jX_{C2})-jR_2X_{C2}}$$

$$\beta=\frac{R_2X_{C2}}{R_1X_{C2}-R_2X_{C1}+R_2X_{C2}+j(R_1R_2-X_{C1}X_{C2})}$$

Applying Barkhausen Criterion

The Imaginary part of β should be 0. This gives

$$R_1 R_2 = \frac{1}{\omega C_1} \frac{1}{\omega C_2} \quad \text{or} \quad \omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

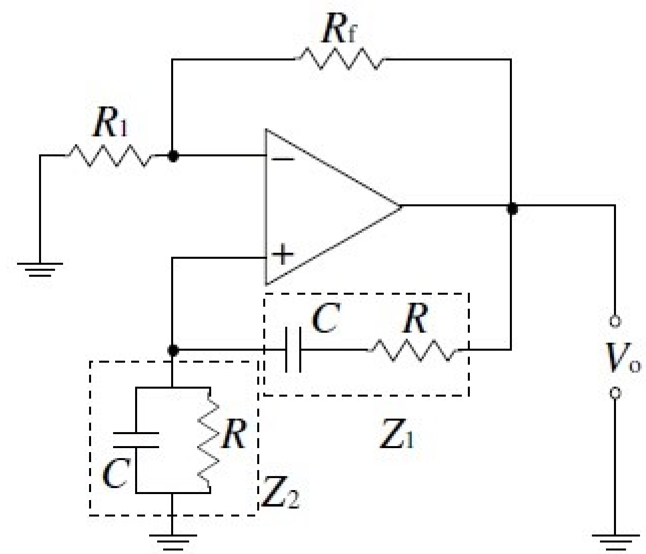
Let $R_1 = R_2 = R$ and $X_{C1} = X_{C2} = X_C$

$$\beta = \frac{R X_C}{3 R X_C + j(R^2 - X_C^2)}$$

At this frequency β= 1/3 and phase shift = 0.
Due to Barkhausen Criterion Loop gain Avβ=1
where Av= Gain of the amplifier.

Wien Bridge Oscillator

- A Wien Bridge oscillator shown here consists of a non-inverting amplifier and a wien bridge as feedback network.



Wien Bridge Oscillator

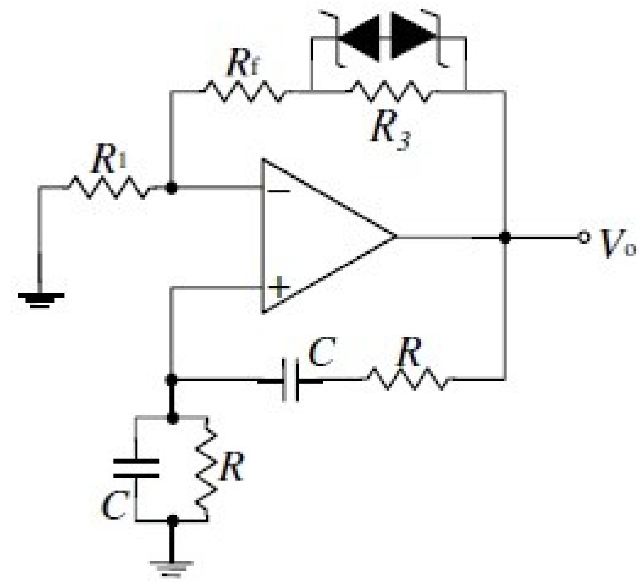
$$A_V\beta = 1 \Rightarrow A_V = 3$$

$$A_V = 1 + \frac{R_f}{R_1} \, so \, \frac{R_f}{R_1} = 2$$

Thus we have the non inverting amplifier with $R_f = 2R_1$.The oscillator will oscillate at frequency $\omega = 1/RC$.

Stabilization of Wien bridge Oscillator

When DC power is applied, the Zener diodes are OFF. So current flows through R3.

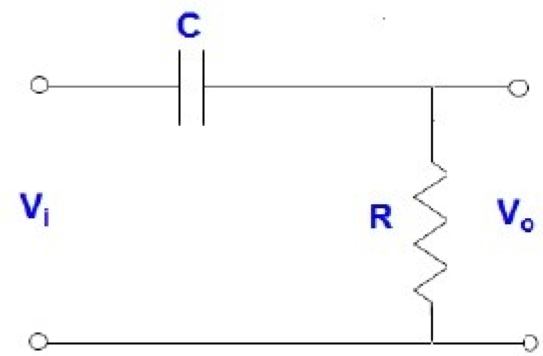


$$A_V = 1 + \frac{R_f + R_3}{R_1} = 3 + \frac{R_3}{R_1} \text{ because } \frac{R_f}{R_1} = 2$$

Initially a small positive feedback signal develops from the noise or transients which gets continuously reinforced resulting in a buildup of the output voltage. When the output voltage reaches the zener breakdown voltage, The zener diodes short R3 and the effective close loop voltage gain becomes 3.

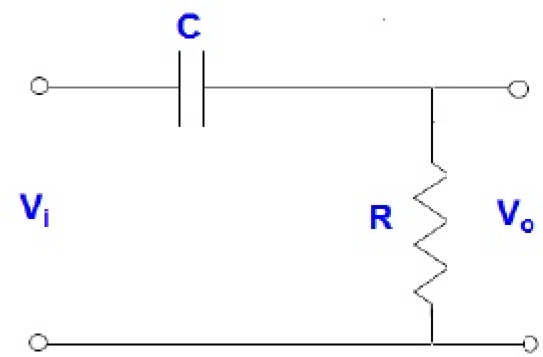
Phase Shift Oscillator

A Phase Shift Oscillator is a feedback oscillator that uses an inverting amplifier together with a feedback network that produces a phase change of π in the signal. To do this it employs a series of RC sections as shown in the figure at right.



Single RC Element

- The attenuation and phase shift due to a single RC element as shown at right can be calculated thus:



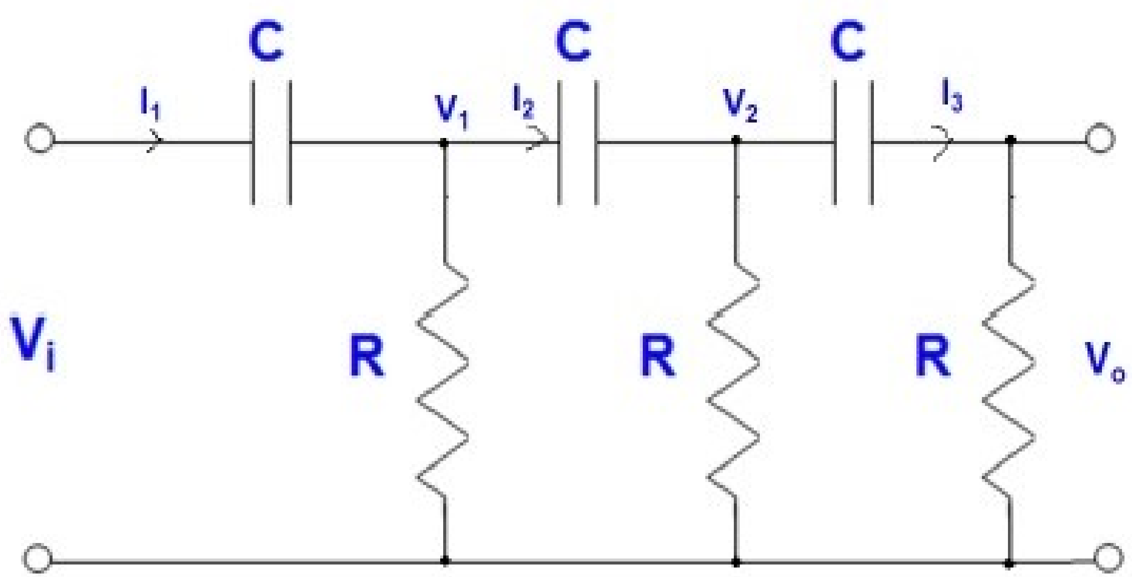
$$V_o = \left(\frac{R}{R - jX_C} \right) V_i$$

$$\tan \varphi = \frac{X_C}{R}$$

$\Phi = 0$ if $X_C = 0$ and $\Phi = 90^o$ if $R = 0$. Neither is practical. So $0^o < \Phi < 90^o$ in practice.

Phase Shift Oscillator

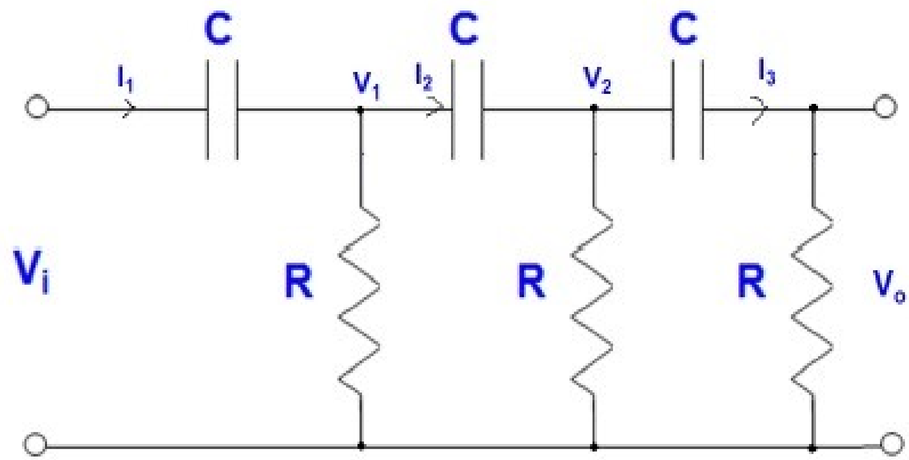
In order to obtain a phase shift of π (180°) we must use three (or more) RC elements in series. An additional phase shift of π is produced by the inverting amplifier thus making total phase shift 2 π.



Phase Shift network

Attenuation due to the network:

At node V2 :



$$V_2 = V_o + I_3 X_C = V_o + \frac{I_3}{j\omega C}$$

Since $I_3 = \frac{V_o}{R}$ we have $V_2 = V_o\left(1 + \frac{1}{j\omega CR}\right)$

$$I_2 = I_3 + \frac{V_2}{R} = \frac{V_o}{R} + \frac{V_o}{R}\left(\frac{1}{1 + j\omega CR}\right)$$ or $$I_2 = \frac{V_o}{R}\left(2 + \frac{1}{j\omega CR}\right)$$

Phase Shift network (contd.)

At node V1 : $V_1 = V_2 + \frac{I_2}{j\omega C} = V_o\left(1 + \frac{3}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right)$

$$I_1 = I_2 + \frac{V_1}{R} = \frac{V_o}{R} + \frac{V_o}{R}\left(3 + \frac{4}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right)$$

We can write the input voltage as:

$$V_i = V_1 + \frac{I_1}{j\omega C} = V_o\left(1 + \frac{6}{j\omega CR} - \frac{5}{\omega^2 C^2 R^2} - \frac{1}{j\omega^3 C^3 R^3}\right)$$

We now apply Barkhausen Criteria:

$$V_i = V_1 + \frac{I_1}{j\omega C} = V_o\left(1 + \frac{6}{j\omega CR} - \frac{5}{\omega^2 C^2 R^2} - \frac{1}{j\omega^3 C^3 R^3}\right)$$

We make the imaginary part as zero.

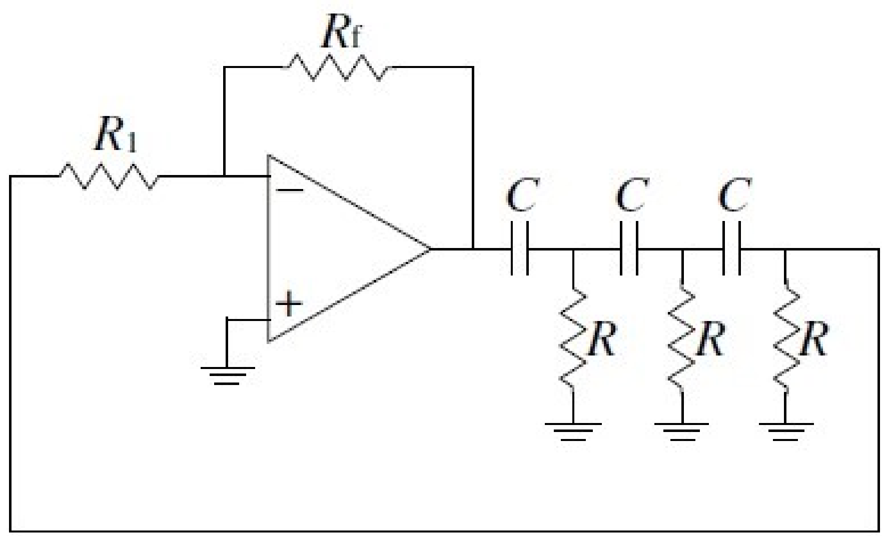
$$\frac{6}{j\omega CR} - \frac{1}{j\omega^3 C^3 R^3} = 0$$ Thus $6\omega^2 C^2 R^2 = 1$

or $\omega = \frac{1}{RC\sqrt{6}}$

At this frequency $V_i = 29\,V_o$ Thus $A_v = -29$

We now connect this network to an inverting amplifier for providing feedback.

Phase Shift Oscillator



The figure above shows a Phase shift Oscillator. The inverting amplifier shown on the left side is set for gain slightly more than 29. R_f / R_1 is a little more than 29.