Islamic University of Technology

EEE 4483
Digital Electronics & Pulse Techniques

Lecture- 12

Oscillator from the Book of Boylsted

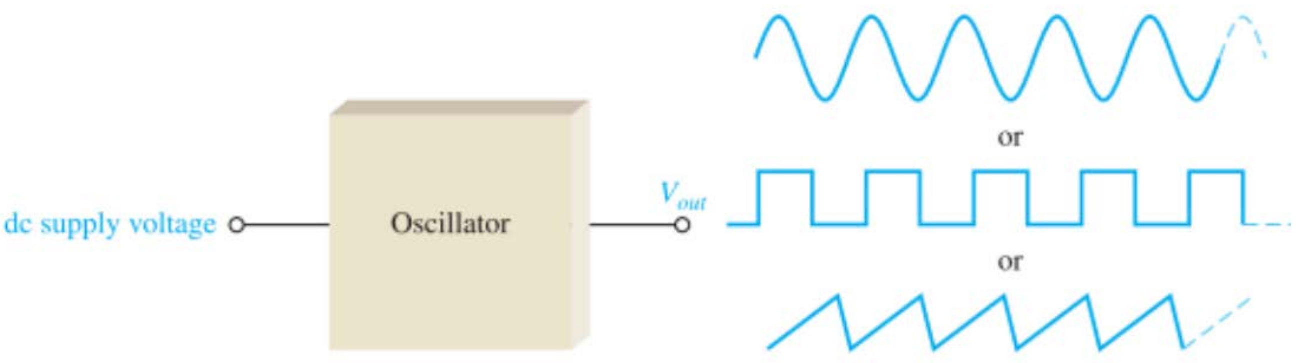
Electronics Devices and Circuit Theory –Robert Boylestad – 11th Ed.

Chapter 14

Page no. 775 – 777, 788 – 791, 798, 800

Osillators

An oscillator provides a source of repetitive A.C. signal across its output terminals without needing any input (except a D.C. supply). The signal generated by the oscillator is usually of constant amplitude. The wave shape and amplitude are determined by the design of the oscillator circuit and choice of component values. The frequency of the output wave may be fixed or variable, depending on the oscillator design.

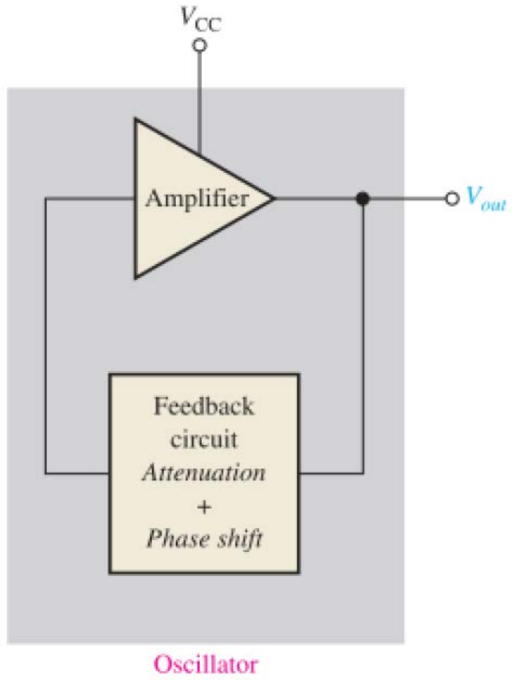


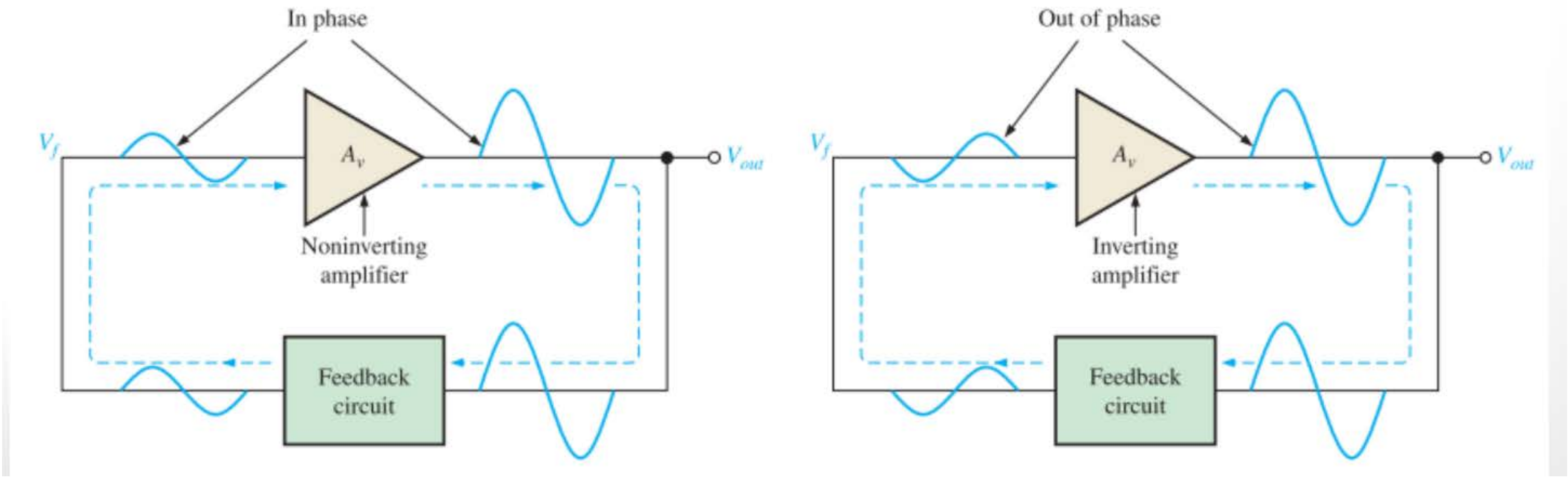
An oscillator converts electrical energy from the dc power supply to periodic waveforms.

- Oscillator – produces a *repetitive signal* from a *DC voltage*.
- The *feedback oscillator* relies on a *positive feedback* of the output to *maintain the oscillations*.
- The *feedback gain* must be kept to *unity* to *keep the output from distorting.*

Positive Feedback

Positive feedback is characterized by the condition wherein a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a reinforcement of the output signal.





Types of Osillators

The output voltage can be either sinusoidal or non sinusoidal, depending on the type of oscillator.

Two major classifications for oscillators are feedback oscillators and relaxation oscillators.

=> Oscillators may be classified by the type of signal they produce.

SINE WAVE OSCILLATORS produce a sine wave output.
RELAXATION OSCILLATORS and ASTABLE MULTIVIBRATORS produce Square waves and rectangular pulses.
SWEEP OSCILLATORS produce sawtooth waves.

Application of Osillators

- Oscillators are used to generate signals, e.g.
  - Used as a local oscillator to transform the RF signals to IF signals in a receiver;
  - Used to generate RF carrier in a transmitter
  - Used to generate clocks in digital systems;
  - Used as sweep circuits in TV sets and CRO.

Basic principles for oscillation

Oscillator is an amplifier with *positive feedback*.

$$V_e = V_s + V_f \quad (1)$$

$$V_f = \beta V_o \quad (2)$$

$$V_o = AV_e = A(V_s + V_f) = A(V_s + \beta V_o) \quad (3)$$

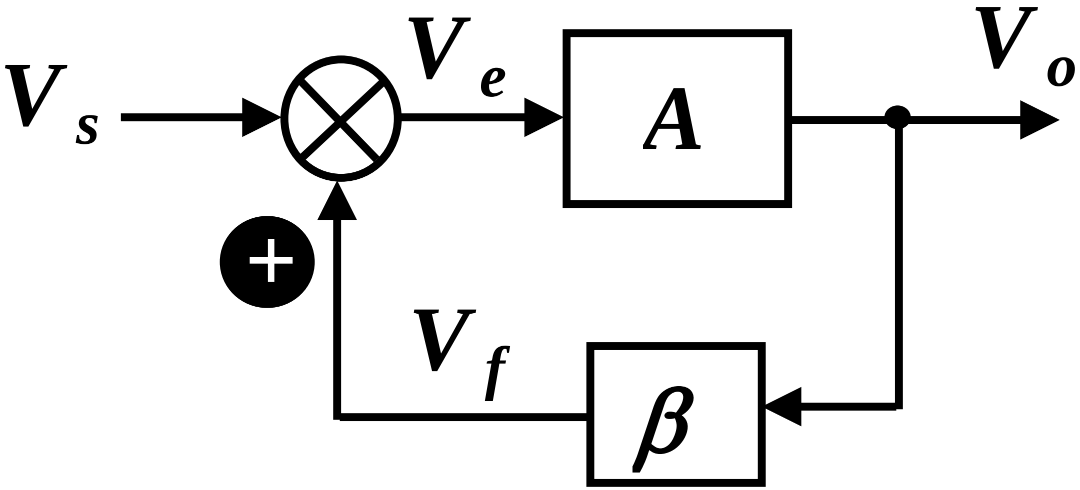
$$V_o = AV_e = A(V_s + V_f) = A(V_s + \beta V_o)$$

$$V_o = AV_s + A\beta V_o$$

$$(1 - A\beta)V_o = AV_s$$

→ The closed loop gain is:

$$\boxed{A_f \equiv \frac{V_o}{V_s} = \frac{A}{(1 - A\beta)}}$$



Basic principles for oscillation : continued ..

- In general A and β are functions of frequency and thus may be written as;

$$\boxed{A_f(s) = \frac{V_o}{V_s}(s) = \frac{A(s)}{1 - A(s)\beta(s)}}$$

$A(s)\beta(s)$ is a *loop gain*

Basic principles for oscillation : continued ..

- Writing $\boxed{T(s) = A(s)\beta(s)}$ the loop gain becomes;

$$\boxed{A_f(s) = \frac{A(s)}{1 - T(s)}}$$

- Replacing *s* with $j\omega$

$$\boxed{A_f(j\omega) = \frac{A(j\omega)}{1 - T(j\omega)}}$$

$$\rightarrow \boxed{T(j\omega) = A(j\omega)\beta(j\omega)}$$

Basic principles for oscillation : continued ..

- At a specific frequency f_0

$$\boxed{T(j\omega_0) = A(j\omega_0)\beta(j\omega_0) = 1}$$

- At this frequency, the closed loop gain will be infinite

$$\boxed{A_f(j\omega_0) = \frac{A(j\omega_0)}{1 - A(j\omega_0)\beta(j\omega_0)}}$$

i.e. the circuit will have finite output for zero input signal – oscillation.

Basic principles for oscillation : continued ..

Thus, the condition for sinusoidal oscillation of frequency f_0 is;

$$\boxed{A(j\omega_0)\beta(j\omega_0) = 1}$$

This is known as Barkhausen criterion.

The frequency of oscillation is solely determined by the phase characteristic of the feedback loop – *the loop oscillates at the frequency for which the phase is zero.*

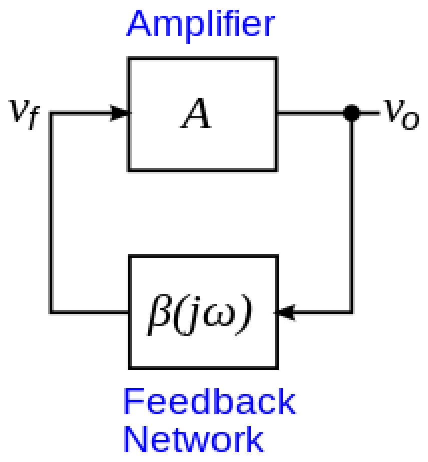
Barkhausen Criterion

Barkhausen criterion are a set of two mathematical conditions which a linear electronic circuit must follow to act as an electronic oscillator.

According to **Barkhausen criterion** for sustained oscillation:

- ❑ The magnitude of the product of open loop gain of the amplifier and the magnitude of the feedback factor is unity, i.e., $|\beta A|=1$ where A is the gain of the amplifying element in the circuit and $\beta(j\omega)$ is the transfer function of the feedback path.

- ❑ The total phase shift around the loop is 0 or integral multiples of 2π



However, it is important to note that **Barkhausen criterion** is a necessary condition for oscillation but not a sufficient condition.

Design Criterion for Oscillators

1. The magnitude of the loop gain must be unity or slightly larger

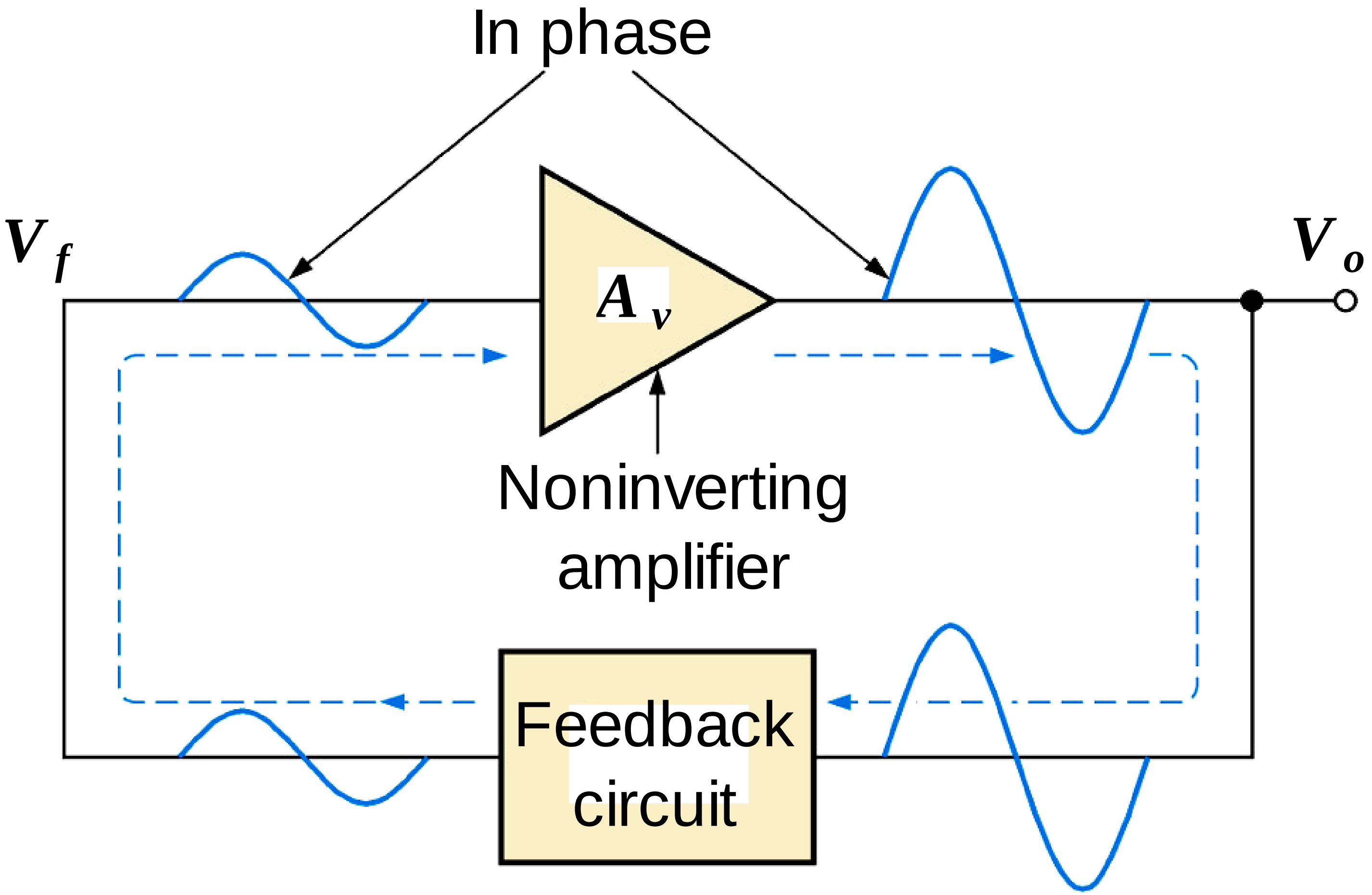
   $$\left|\boldsymbol{A\beta}\right| = \mathbf{1}$$ – *Barkhaussen criterion*

2. Total phase shift, ϕ of the loop gain must be

   $$N \times 360^\circ$$

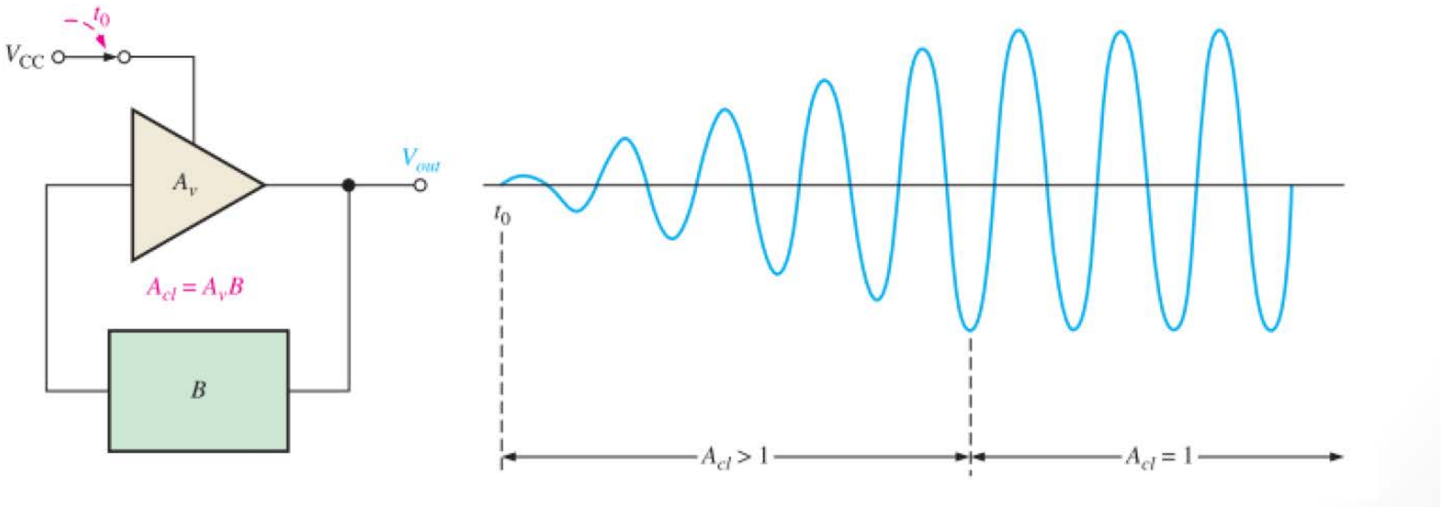
   where N=0, 1, 2, …

Design Criterion for Oscillators



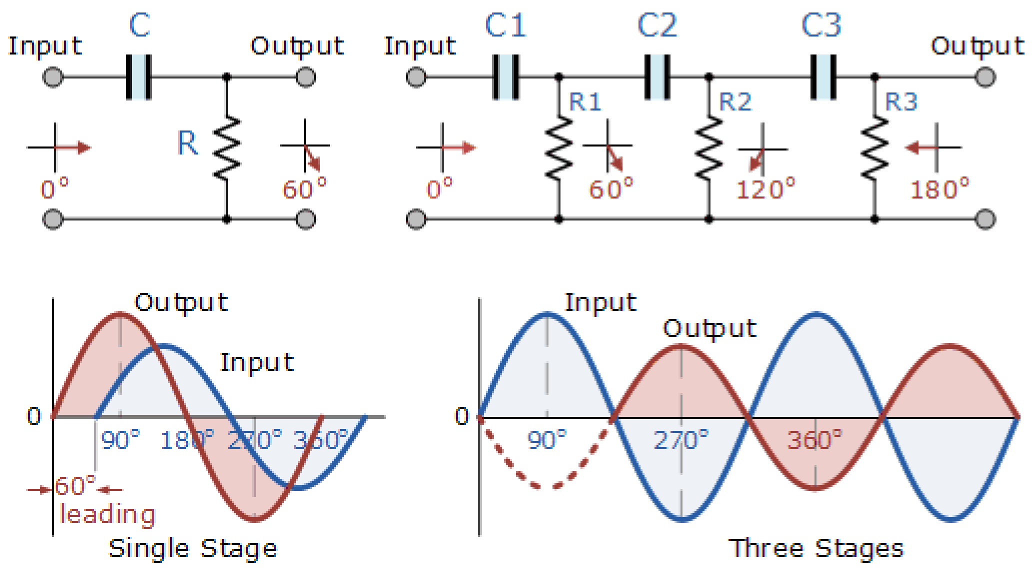
Start up Conditions

- For oscillation to begin, the voltage gain around the positive feedback loop must be greater than 1 so that the amplitude of the output can build up to a desired level.
- The gain must then decrease to 1 so that the output stays at the desired level and oscillation is sustained.
- Initially, a small positive feedback voltage develops from thermally produced broad-band noise in the resistors or other components or from power supply turn-on transients.



RC Phase-shift Network

The circuit on the right shows a single resistor-capacitor network whose output voltage "leads" the input voltage by some angle less than 90o. An ideal single-pole RC circuit would produce a phase shift of exactly 90º, and because 180º of phase shift is required for oscillation, at least two single-poles must be used in an RC oscillator design.



RC Phase Angle

$$X_C = \frac{1}{2\pi f C} \quad ; R = R$$

$$Z = \sqrt{R^2 + (X_C)^2}$$

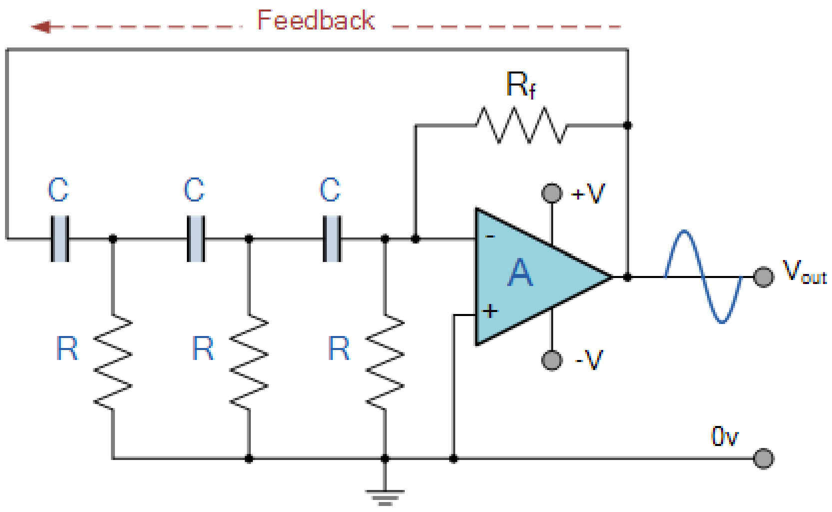
$$\therefore \quad \varphi = tan^{-1}\frac{X_C}{R}$$

Where: X_C is the Capacitive Reactance of the capacitor, R is the Resistance of the resistor, and *f* is the Frequency.

In the example above, the values of R and C have been chosen so that at the required frequency the output voltage leads the input voltage by an angle of about 60º. Then the phase angle between each successive RC section increases by another 60º giving a phase difference between the input and output of 180º (3 x 60º) as shown by the following vector diagram.

OP-Amp RC Oscillator Circuit

As the feedback is connected to the inverting input, the operational amplifier is therefore connected in its **inverting amplifier** configuration which produces the required 180° phase shift while the RC network produces the other 180° phase shift at the required frequency (180° + 180°).



Although it is possible to cascade together only two single-pole RC stages to provide the required 180° of phase shift (90° + 90°), the stability of the oscillator at low frequencies is generally poor.

One of the most important features of an RC Oscillator is its frequency stability which is its ability to provide a constant frequency *sine-wave* output under varying load conditions. By cascading three or even four RC stages together (4 x 45°), the stability of the oscillator can be greatly improved.

RC Oscillators are stable and provide a well-shaped sine wave output with the frequency being proportional to 1/RC and therefore, a wider frequency range is possible when using a variable capacitor. However, RC Oscillators are restricted to frequency applications because of their bandwidth limitations to produce the desired phase shift at high frequencies.

RC Oscillator Circuit : continued ..

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_r is the Output Frequency in Hertz

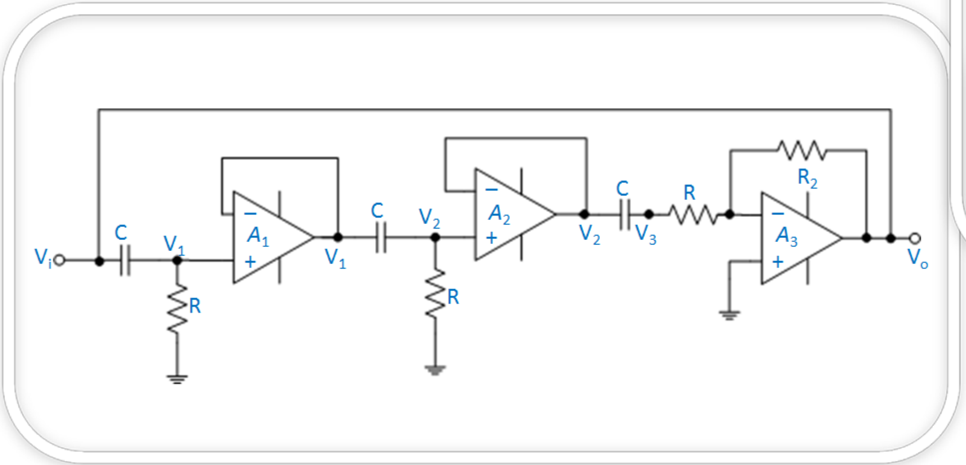
R is the Resistance in Ohms

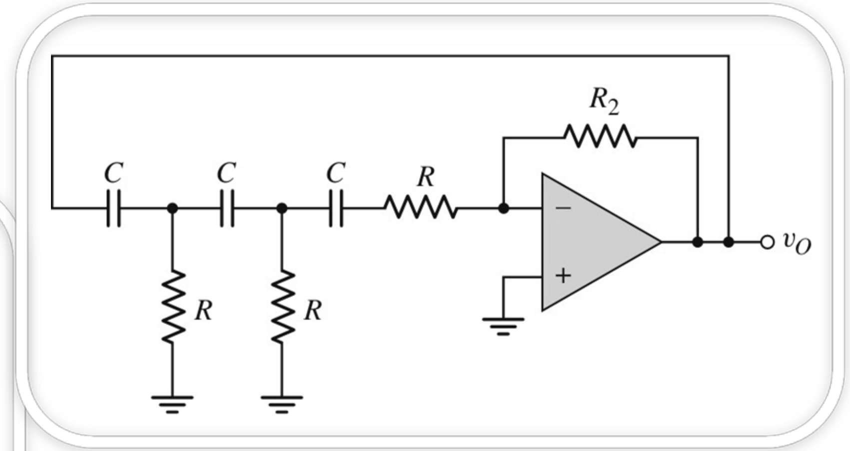
C is the Capacitance in Farads

N is the number of RC stages

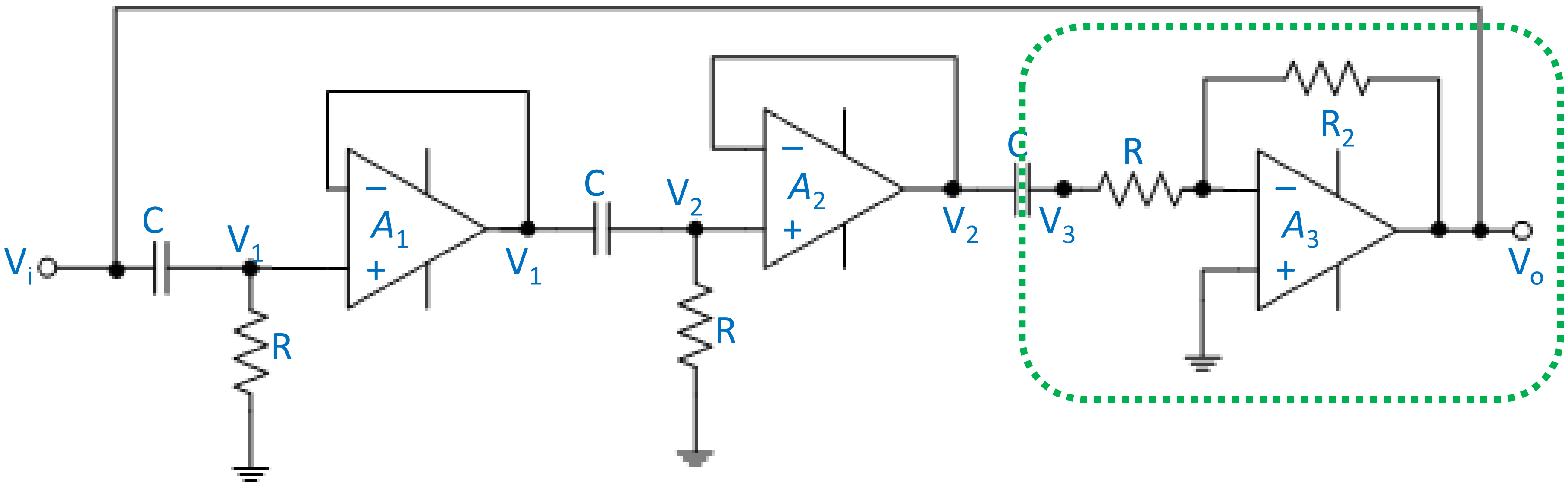
Phase Shift Oscillator

- The phase shift oscillator utilizes *three (3) RC circuits* to provide *180° phase shift.*
- When coupled with an *inverting amplifier with -180°*, it provides the necessary feedback to sustain oscillations.





Phase Shift Oscillator : continued ..



$$I_3 = \frac{V_3}{R}$$

$$I_{fb} = \frac{V_o}{R_2}$$

$\rightarrow$ $\rightarrow$

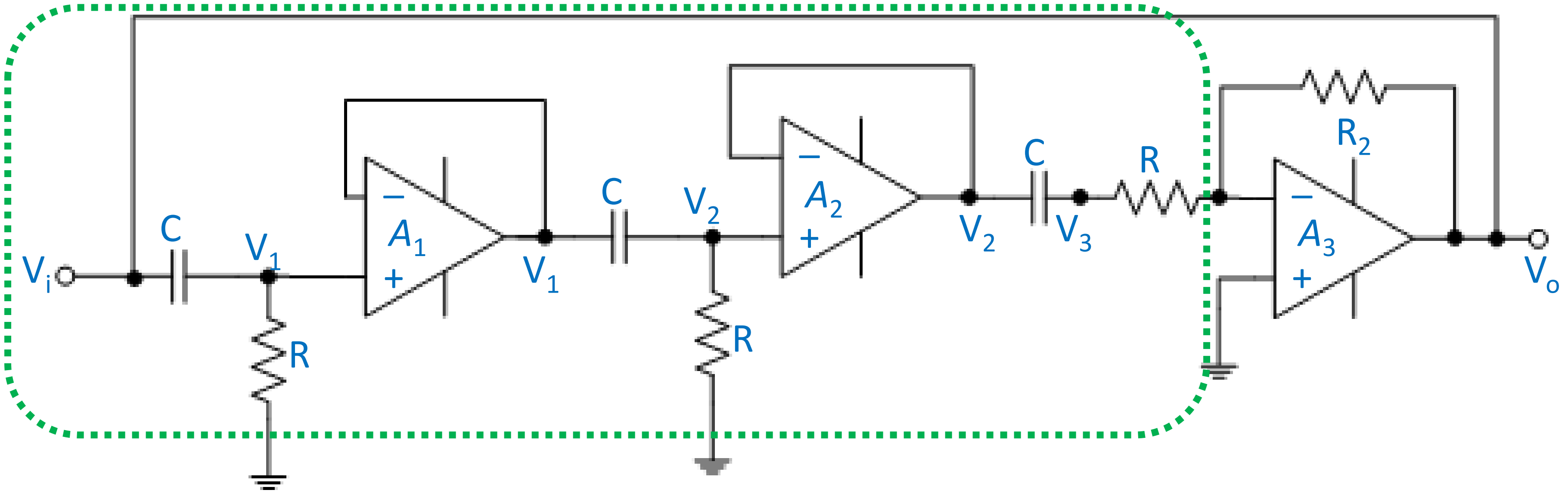
$$I_3 = I_{fb}$$

$$\frac{V_3}{R} = \frac{V_o}{R_2}$$

$\rightarrow$ $\rightarrow$

$$A(s) = \left|\frac{v_o}{v_3}\right| = \frac{R_2}{R}$$

Phase Shift Oscillator : continued ..



$$v_1 = \left(\frac{sRC}{1+sRC}\right) v_i$$

$$v_2 = \left(\frac{sRC}{1+sRC}\right)^2 v_i$$

$$v_3 = \left(\frac{sRC}{1+sRC}\right)^3 v_i$$

$$\beta(s) = \frac{v_3}{v_i} = \left(\frac{sRC}{1+sRC}\right)^3$$

Phase Shift Oscillator : continued ..

$\therefore$ Loop gain, T(s):

$$T(s) = A(s)\beta(s) = \left(\frac{R_2}{R}\right)\left(\frac{sRC}{1+sRC}\right)^3$$

Phase Shift Oscillator : continued ..

Substitute s=jω,

$$T(j\omega) = \left(\frac{R_2}{R}\right)\left(\frac{j\omega RC}{1 + j\omega RC}\right)^3$$

$$T(j\omega) = -\left(\frac{R_2}{R}\right)\frac{(j\omega RC)(\omega RC)^2}{\left[1 - 3\omega^2 R^2 C^2\right] + j\omega RC\left[3 - \omega^2 R^2 C^2\right]}$$

Phase Shift Oscillator : continued ..

To satisfy condition $T(j\omega_o) = 1$, real component must be zero since the numerator is purely imaginary.

$$T(j\omega) = -\left(\frac{R_2}{R}\right)\frac{\boxed{(j\omega RC)(\omega RC)^2}}{\left[1-3\omega^2R^2C^2\right]+j\omega RC\left[3-\omega^2R^2C^2\right]}$$

To get the oscillation frequency:

$$1-3\omega^2R^2C^2 = 0$$

Substitute ω_o in equation:

$$\omega_0 = \frac{1}{\sqrt{3}RC}$$

Phase Shift Oscillator : continued ..

- To satisfy condition $|T(j\omega_o)|=1$,

$$\left|T(j\omega_o)\right| = -\left(\frac{R_2}{R}\right)\frac{(j/\sqrt{3})(1/3)}{0+(j/\sqrt{3})\left[3-(1/3)\right]}$$

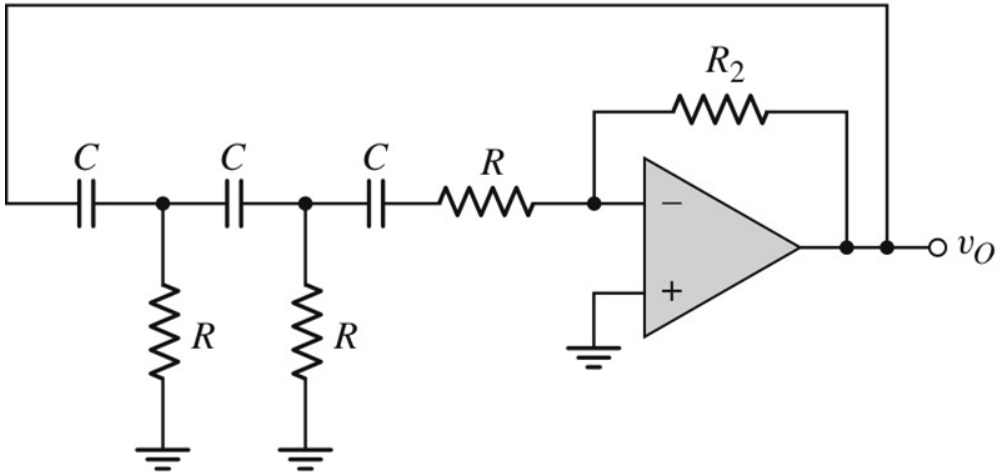
$$\underbrace{|1|}_{T} = \underbrace{-\left(\frac{R_2}{R}\right)}_{A}\underbrace{\left(\frac{1}{8}\right)}_{\beta} \rightarrow \boxed{\frac{R_2}{R}=8}$$

To start oscillation, the ratio R_2/R must be slightly greater than 8.

Phase Shift Oscillator : continued ..

- The *gain must be at least 29* to maintain the oscillations.
- The frequency of resonance for the this type is similar to any RC circuit oscillator:

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

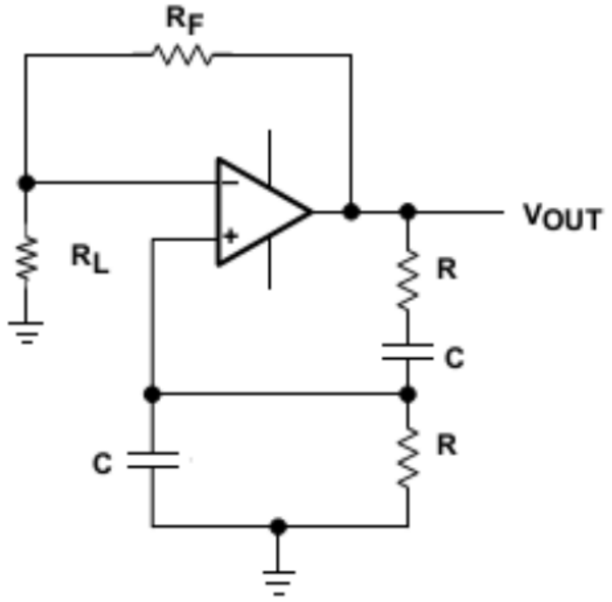


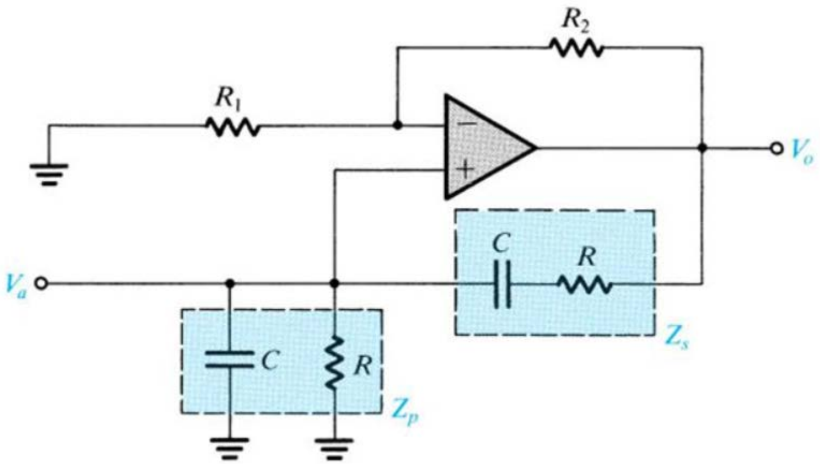
Wein Bridge Oscillator

The Wien bridge oscillator is an electronic oscillator and produces the sine waves. It is a two stage RC circuit amplifier circuit and it has high quality of resonant frequency, low distortion, and also in the tuning.

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 but the phase shift of the output signal is considerably different from the previous phase shift RC Oscillator.

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

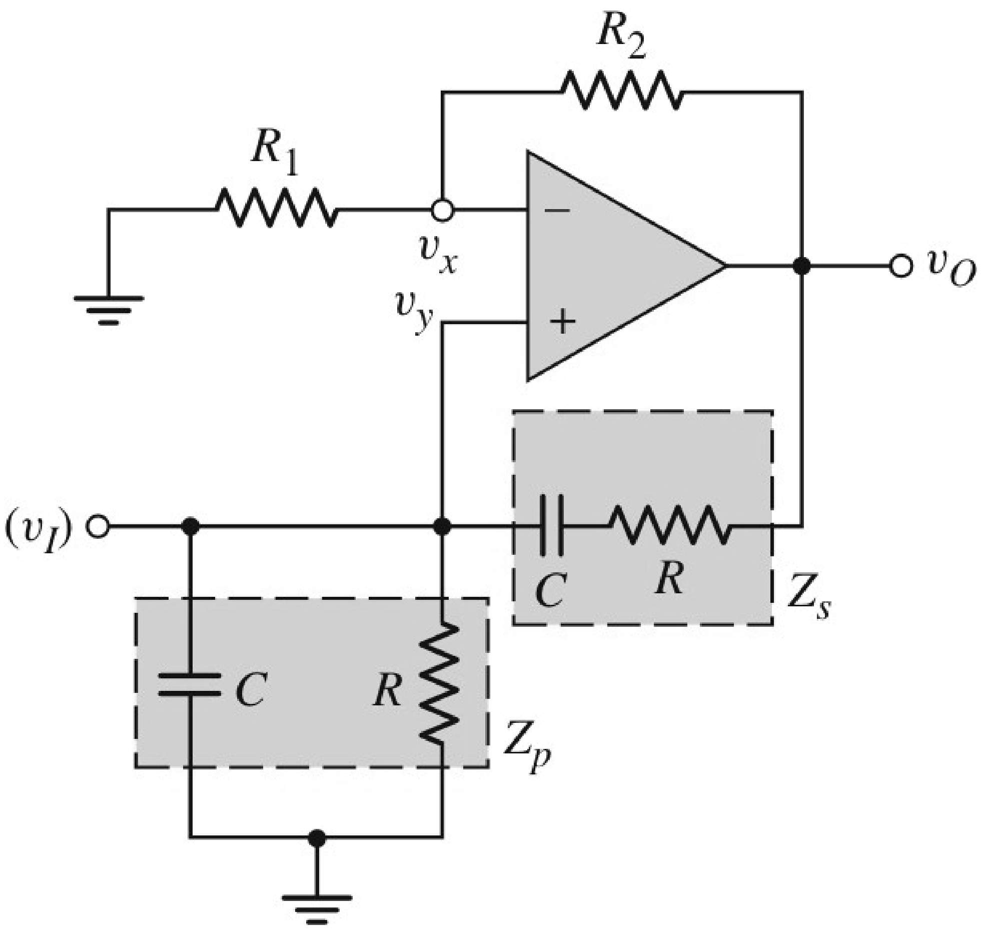




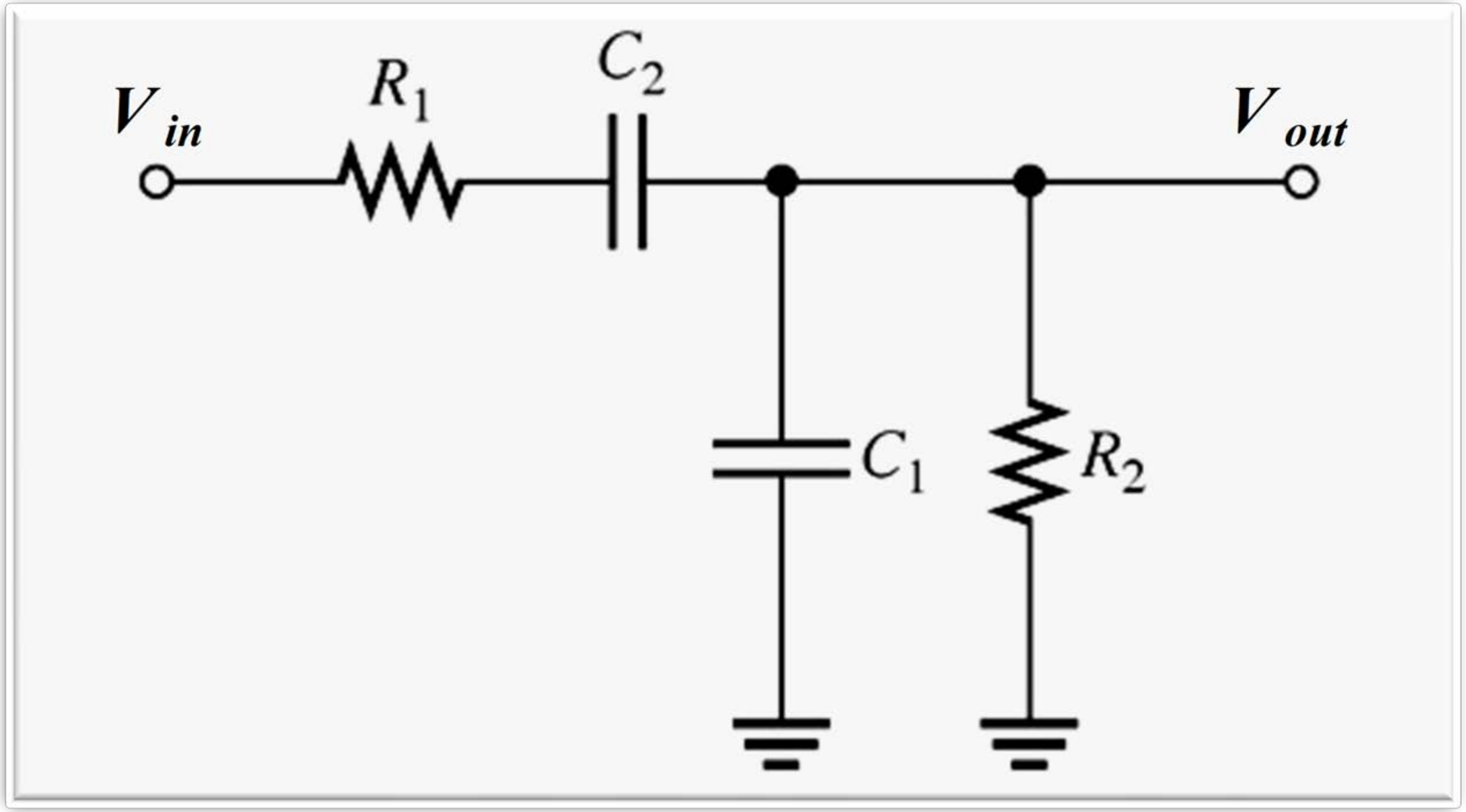
Wein Bridge Oscillator : contd ..

The *lead-lag circuit* is in the positive feedback loop of Wien-bridge oscillator. The *voltage divider limits the gain*.

The lead lag circuit is basically a band-pass with a narrow bandwidth.



Wein Bridge Oscillator : contd ..



Lead-lag circuit

Wein Bridge Oscillator : contd ..

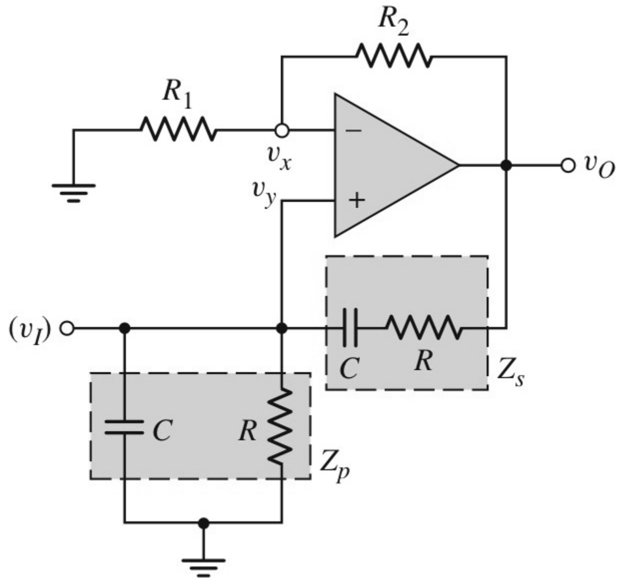
The loop gain for the oscillator is;

$$T(s) = A(s)\beta(s) = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{Z_p}{Z_p + Z_s}\right)$$

where;

$$Z_p = \frac{R}{1 + sRC}$$

and $$Z_s = \frac{1 + sRC}{sC}$$



Wein Bridge Oscillator : contd ..

Hence;

$$T(s) = \left(1 + \frac{R_2}{R_1}\right)\left[\frac{1}{3 + sRC + (1/sRC)}\right]$$

Substitute s=jω,

$$T(j\omega) = \left(1 + \frac{R_2}{R_1}\right)\left[\frac{1}{3 + j\omega RC + (1/j\omega RC)}\right]$$

Wein Bridge Oscillator : contd ..

For oscillation frequency, f_0;

$$T(j\omega_0) = \left(1 + \frac{R_2}{R_1}\right)\left[\frac{1}{3 + j\omega_0 RC + (1/j\omega_0 RC)}\right]$$

Wein Bridge Oscillator : contd ..

- Since at the frequency of oscillation,
  - → $T(j\omega)$ must be real (for zero phase condition)
  - → The imaginary component must be zero;

$$\boxed{j\omega_0 RC + \frac{1}{j\omega_0 RC} = 0}$$

Thus;

$$\boxed{\omega_0 = \frac{1}{RC}}$$

- where the frequency of resonance:

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

Wein Bridge Oscillator : contd ..

$$j\omega_0 RC + \frac{1}{j\omega_0 RC} = 0$$

$$==> \ j\omega_0 RC = -\frac{1}{j\omega_0 RC}$$

$$==> (j\omega_0 RC)^2 = -1$$

$$==> \ j^2(\omega_0 RC)^2 = -1$$

$$==> -1.(\omega_0 RC)^2 = -1$$

$$==> (\omega_0 RC)^2 = 1$$

$$==> \omega_0 RC = 1$$

$$==> \omega_0 = \frac{1}{RC}$$

Wein Bridge Oscillator : contd ..

Insert ω_o function into the previous $T\,(\,j\omega_o)$ equation;

$$T(j\omega_0) = \left(1+\frac{R_2}{R_1}\right)\left[\frac{1}{3+j\omega_0 RC + (1/j\omega_0 RC)}\right]$$

$$= \left(1+\frac{R_2}{R_1}\right)\left[\frac{1}{3+j+(1/j)}\right]$$

$$= \left(1+\frac{R_2}{R_1}\right)\left(\frac{1}{3}\right)$$

Wein Bridge Oscillator : contd ..

The magnitude condition is, T = 1;

$$\boxed{1 = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{1}{3}\right)} \rightarrow \boxed{\frac{R_2}{R_1} = 2}$$

To start oscillation, the ratio R_2/R_1 must be slightly greater than 2.

$$\underbrace{1}_{T} = \overbrace{\left(1 + \frac{R_2}{R_1}\right)}^{A}\overbrace{\left(\frac{1}{3}\right)}^{\beta}$$

Wein Bridge Oscillator : contd ..

With the ratio; $$\boxed{\frac{R_2}{R_1} = 2}$$

then; $$\boxed{K \equiv 1 + \frac{R_2}{R_1} = 3}$$

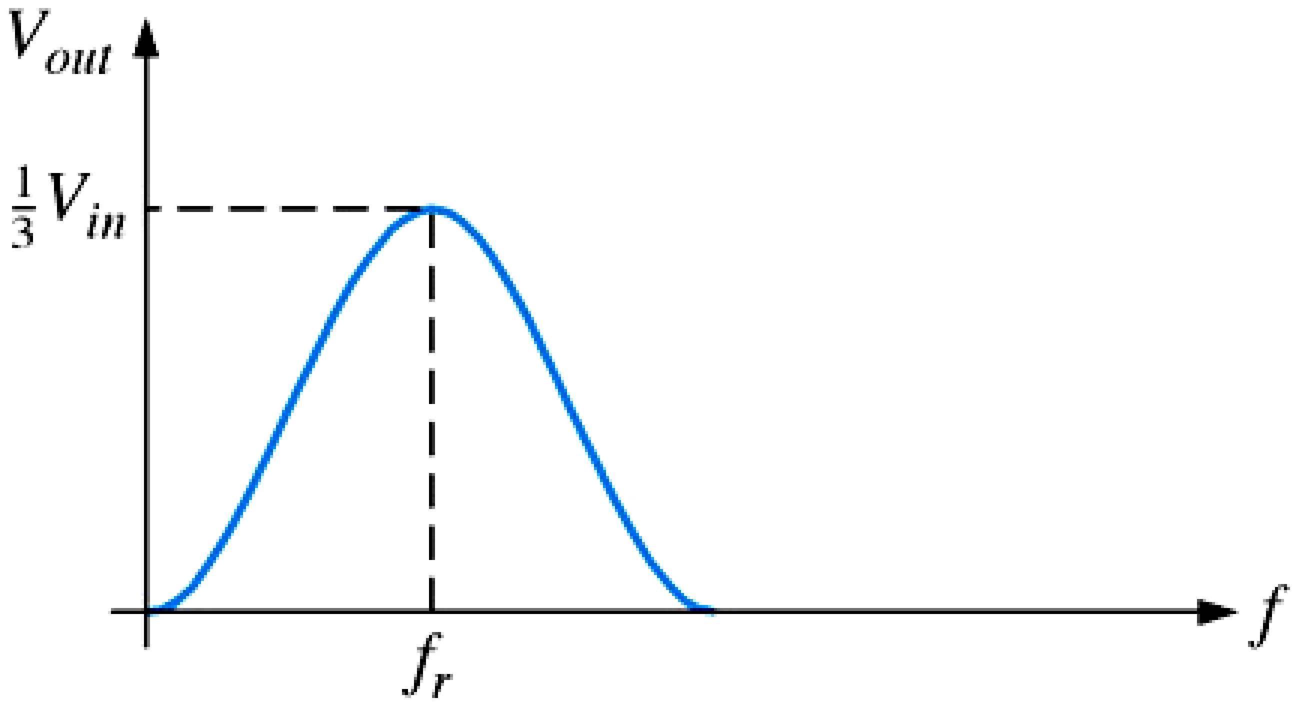
To ensure oscillation, the ratio R_2/R_1 must be slightly greater than 2.

$K = 3$ ensures the loop gain of unity – oscillation

- $K > 3$ **: growing oscillations**
- $K < 3$ **: decreasing oscillations**

Wein Bridge Oscillator : contd ..

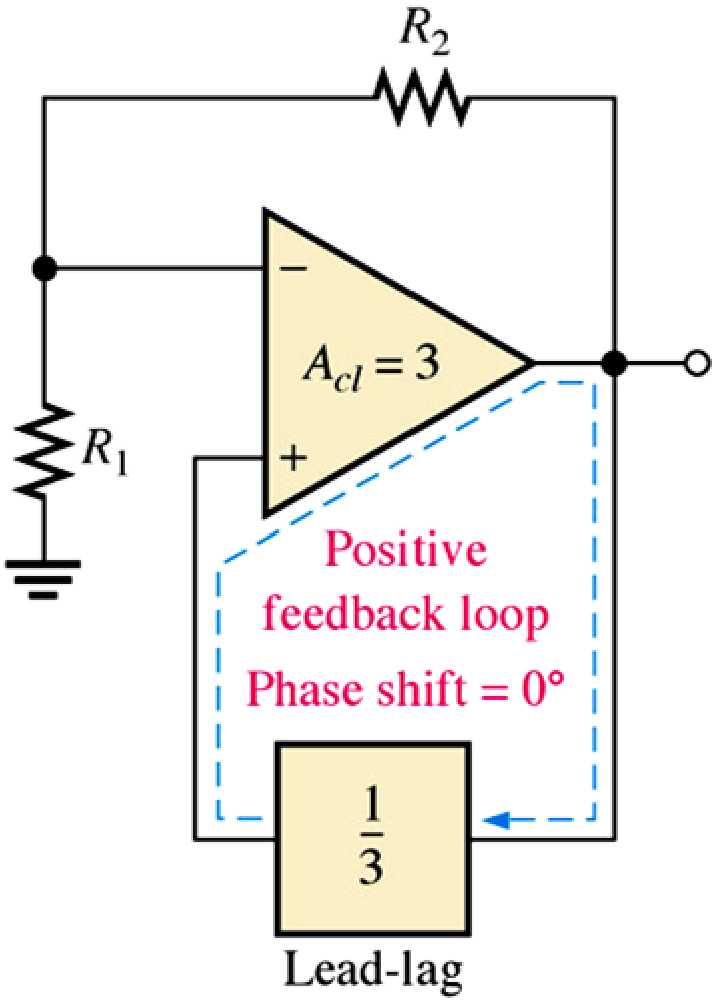
The lead-lag circuit of a Wien-bridge oscillator *reduces* the input signal by **1/3** and yields a response curve as shown.



Wein Bridge Oscillator : contd ..

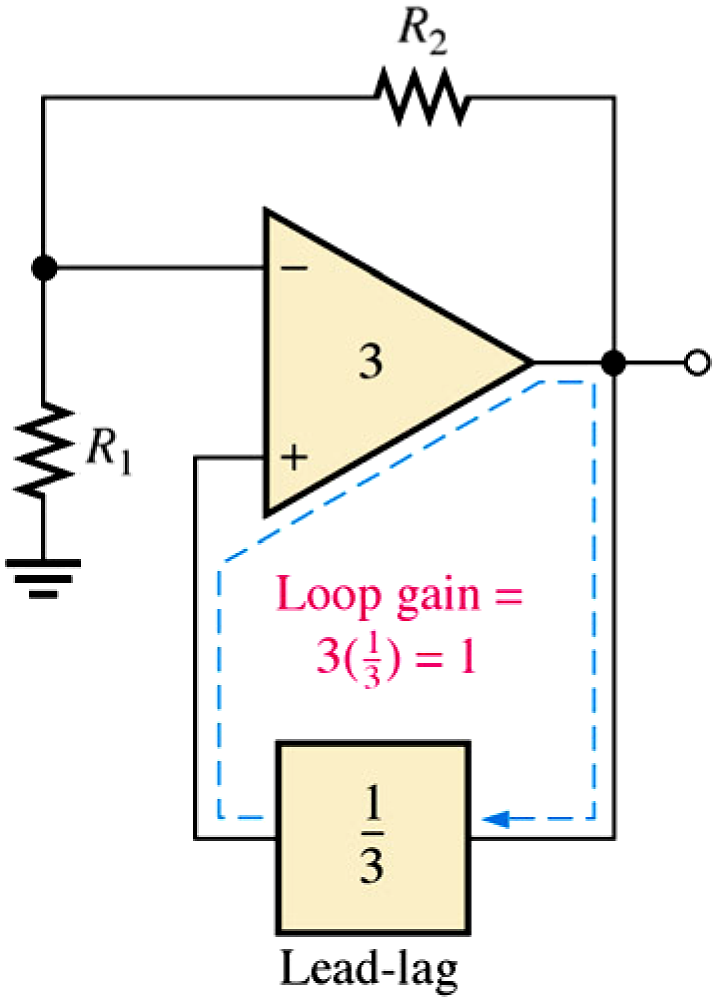
Since there is a loss of about 1/3 of the signal in the positive feedback loop, the **voltage-divider ratio** must be adjusted so that a positive feedback loop gain of **1** is produced.

This requires a closed-loop gain of 3. The ratio of R_1 and R_2 can be set to achieve this.



(a) The phase shift around the loop is 0°.

Wein Bridge Oscillator : contd ..

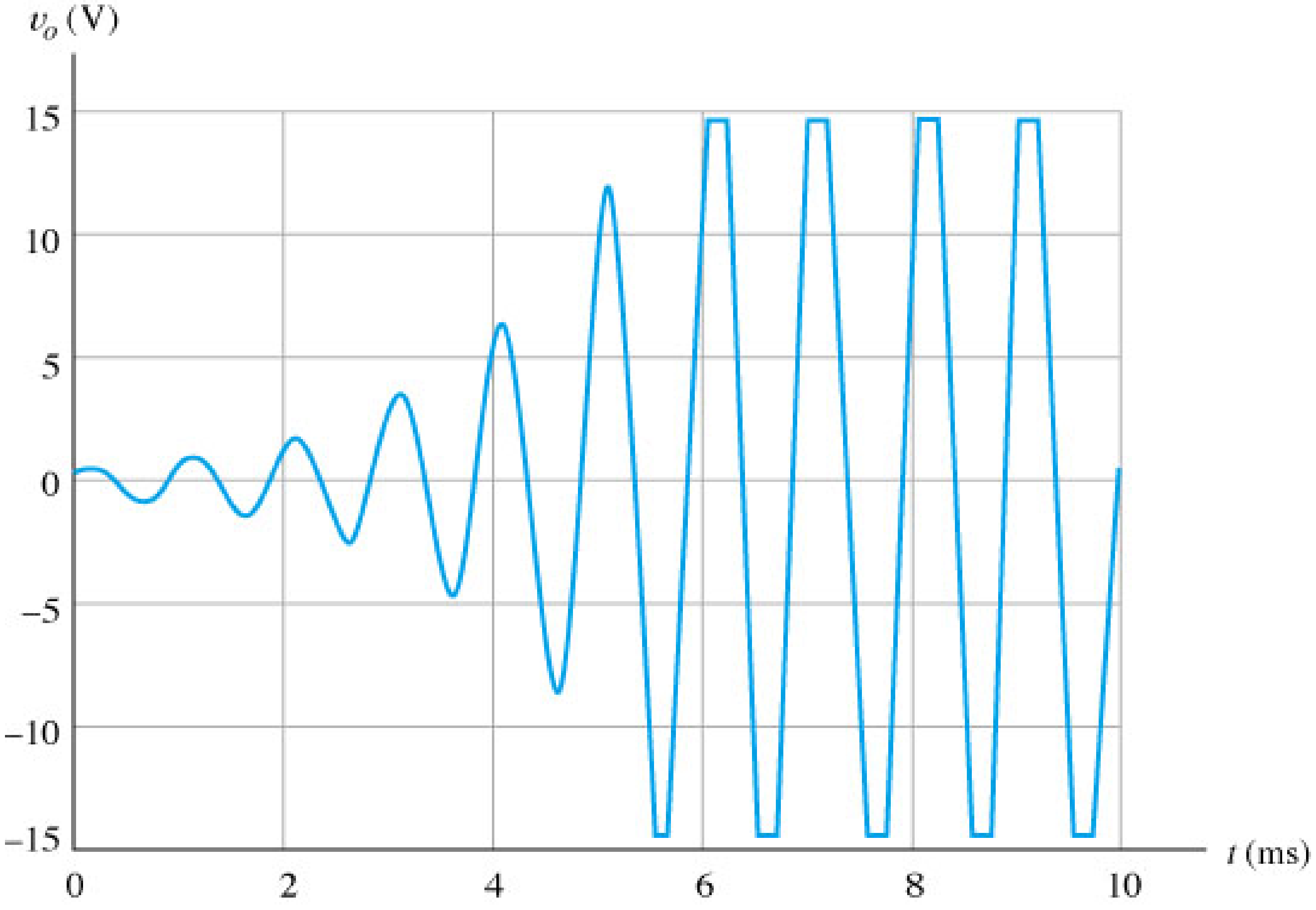


(b) The voltage gain around the loop is 1.

The gain around the loop must equal unity (1).

$$\underbrace{1}_{T} = \underbrace{\left(1+\frac{R_2}{R_1}\right)}_{A}\underbrace{\left(\frac{1}{3}\right)}_{\beta}$$

Wein Bridge Oscillator output



Example of output voltage of the oscillator.

Crystal-Controlled Oscillator

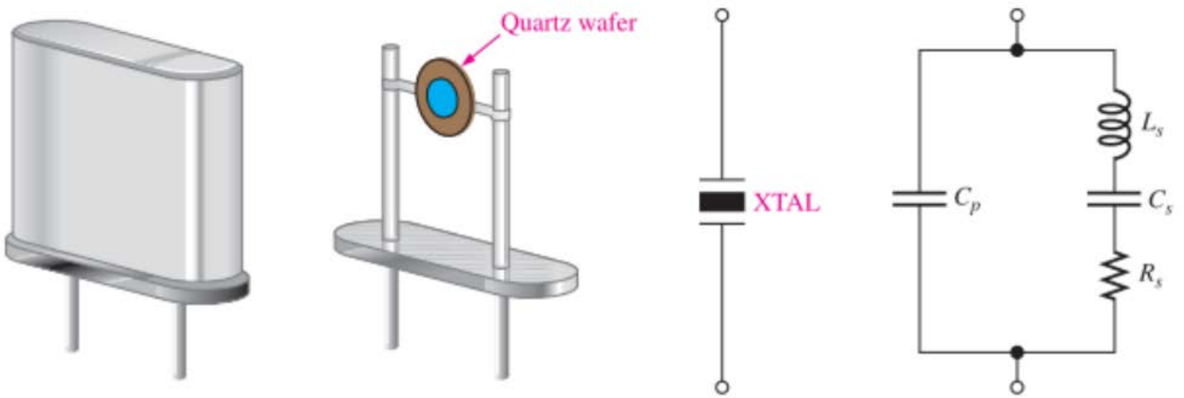
The most stable and accurate type of feedback oscillator uses a piezoelectric crystal in the feedback loop to control the frequency.

• Quartz is one type of crystalline substance found in nature that exhibits a property called the piezoelectric effect.

• When a changing mechanical stress is applied across the crystal to cause it to vibrate, a voltage develops at the frequency of mechanical vibration.

• Conversely, when an ac voltage is applied across the crystal, it vibrates at the frequency of the applied voltage.

• The greatest vibration occurs at the crystal's natural resonant frequency, which is determined by the physical dimensions and by the way the crystal is cut.



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

Crystal-Controlled Oscillator

A great advantage of the crystal is that it exhibits a very high Q.

• The impedance of the crystal is minimum at the series resonant frequency, thus providing maximum feedback.

• a crystal is used as a series resonant tank circuit.

• The crystal tuning capacitor, C_c is used to “fine tune” the oscillator frequency by “pulling” the resonant frequency of the crystal slightly up or down.

Modes:

• Piezoelectric crystals can oscillate in either of two modes - fundamental or overtone.

• The fundamental frequency of a crystal is the lowest frequency at which it is naturally resonant.

• The fundamental frequency depends on the crystal’s mechanical dimensions, type of cut, .. etc.

• Usually it’s less than 20 MHz.

• Overtones are approximate integer multiples of the fundamental frequency.

• Many crystal oscillators are available in integrated circuit packages.

Crystal Oscillator

An op-amp can be used in a crystal oscillator as shown in the figure. The crystal is connected in the series-resonant path and operates at the crystal series-resonant frequency. The present circuit has a high gain, so that an output square-wave signal results as shown in the figure. A pair of Zener diodes is shown at the output to provide output amplitude at exactly the Zener voltage (V_Z).