Basics of Oscillators: Criteria for oscillation:

The canonical form of a feedback system is shown in Figure 5 . 1, and Equation 1 describes the performance of any feedback system (an amplifier with passive feedback Components constitute a feedback system).

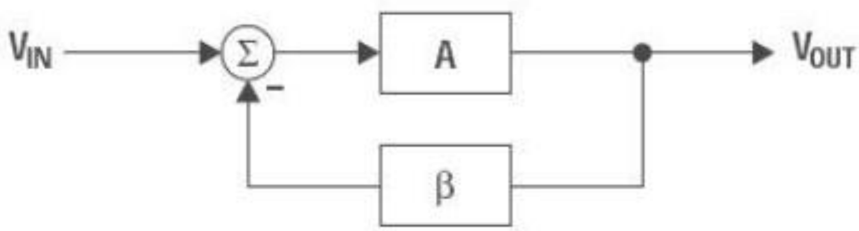

Fig. 5.1 Canonical form of feedback circuit

$$\frac{V_{OUT}}{V_{IN}} = \frac{A}{1 + A\beta} \qquad (1)$$

Oscillation results from an unstable state; i.e., the feedback system can't find a stable state because its transfer function can't be satisfied. Equation 1 becomes unstable when $(1+A\beta) = 0$ because A/0 is an undefined state. Thus, the key to designing an oscillator is to insure that $A\beta = -1$ (called the Barkhausen criterion), or using complex math the equivalent expression is $A\beta = 1\ -180°$. The 180° phase shift criterion applies to negative feedback systems, and 0° phase shift applies to positive feedback systems.

The output voltage of a feedback system heads for infinite voltage when $A\beta = -1$. When the output voltage approaches either power rail, the active devices in the amplifiers change gain, causing the value of A to change so the value of $A\beta \neq 1$;

thus, the charge to infinite voltage slows down and eventually halts. At this point one of three things can occur.

First, nonlinearity in saturation or cutoff can cause the system to become stable and lock

up.

Second, the initial charge can cause the system to saturate (or cut off) and stay that way for a long time before it becomes linear and heads for the opposite power rail.

Third, the system stays linear and reverses direction, heading for the opposite power rail. Alternative two produces highly distorted oscillations (usually quasi square waves), and the resulting oscillators are called relaxation oscillators. Alternative three produces sine wave oscillators.

Phase Shift in Oscillators:

The 180° phase shift in the equation $A\beta = 1 \quad -180°$ is introduced by active and passive components. The phase shift contributed by active components is minimized because it varies with temperature, has a wide initial tolerance, and is device dependent.

Amplifiers are selected such that they contribute little or no phase shift at the oscillation frequency. A single pole RL or RC circuit contributes up to 90° phase shift per pole, and because 180° is required for oscillation, at least two poles must be used in oscillator design.

An LC circuit has two poles; thus, it contributes up to 180° phase shift per pole pair, but LC and LR oscillators are not considered here because low frequency inductors are expensive, heavy, bulky, and non-ideal. LC oscillators are designed in high frequency applications beyond the frequency range of voltage feedback op amps, where the inductor size, weight, and cost are less significant.

Multiple RC sections are used in low-frequency oscillator design in lieu of inductors. Phase shift determines the oscillation frequency because the circuit oscillates at the frequency that accumulates –180° phase shift. The rate of change of phase with frequency, dS/dt, determines frequencystability.

When buffered RC sections (an op amp buffer provides high input and low output impedance) are cascaded, the phase shift multiplies by the number of sections, n (see Figure 2).

Although two cascaded RC sections provide 180° phase shift, dS/dt at the oscillator frequency is low, thus oscillators made with two cascaded RC sections have poor frequency stability. Three equal cascaded RC filter sections have a higher dS/dt, and the resulting oscillator has improved frequency stability.

Adding a fourth RC section produces an oscillator with an excellent dS/dt, thus this is the most stable oscillator configuration. Four sections are the maximum number used

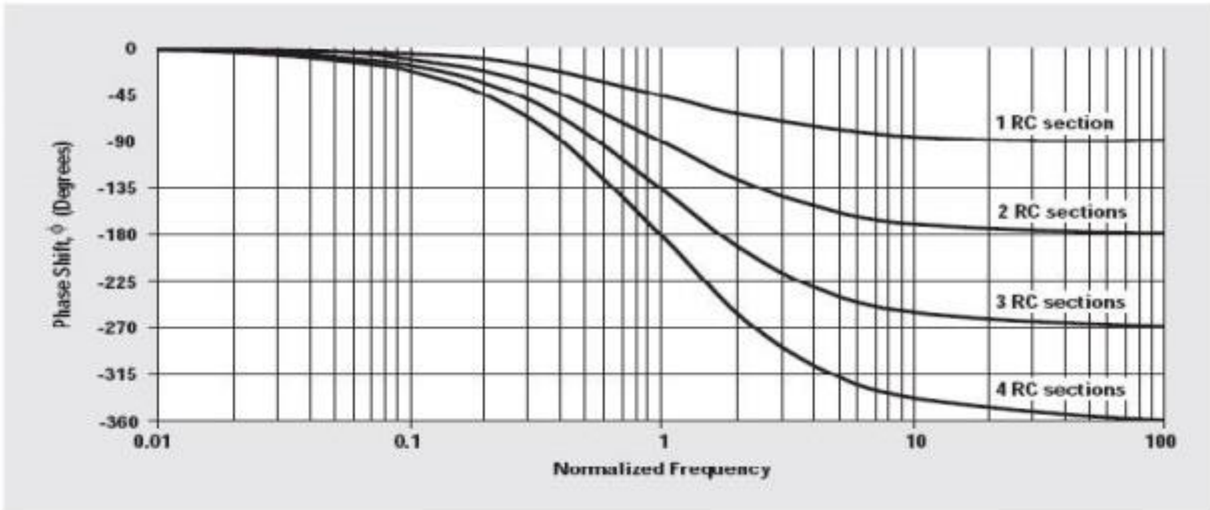

Figure 5.2 Phase plot of RC sections

because op amps come in quad packages, and the four-section oscillator yields four sine waves that are 45° phase shifted relative to each other, so this oscillator can be used to obtain sine/cosine or quadrature sine waves.

Applications

Crystal or ceramic resonators make the most stable oscillators because resonators have an extremely high dS/dt resulting from their non-linear properties.

Resonators are used for high- frequency oscillators, but low-frequency oscillators do not use resonators because of size, weight, and cost restrictions.

Op amps are not used with crystal or ceramic resonator oscillators because op amps have low bandwidth. It is more cost-effective to build a high- frequency crystal oscillator and count down the output to obtain a low frequency than it is to use a low-frequency resonator.

Gain in Oscillators:

The oscillator gain must equal one ($A\beta = 1\angle{-180°}$) at the oscillation frequency. The circuit becomes stable when the gain exceeds one and oscillations cease. When the gain exceeds one with a phase shift of –180°, the active device non-linearity reduces the gain to one.

The non-linearity happens when the amplifier swings close to either power rail because cutoff or saturation reduces the active device (transistor) gain. The paradox is that worst-case design practice requires nominal gains exceeding one for manufacturability, but excess gain causes more distortion of the output sine wave.

When the gain is too low, oscillations cease under worst-case conditions, and when the gain is too high, the output wave form looks more like a square wave than a sine wave.

Distortion is a direct result of excess gain overdriving the amplifier; thus, gain must be carefully controlled in low distortion oscillators.

Phase-shift oscillators have distortion, but they achieve low-distortion output voltages because cascaded RC sections act as distortion filters. Also, buffered phase-shift oscillators have low distortion because the gain is controlled and distributed among the buffers.

sine wave oscillator circuits use phase shifting techniques that usually employ

- Two RC tuning networks, and
- Complex amplitude limiting circuitry

RC Phase Shift Oscillator

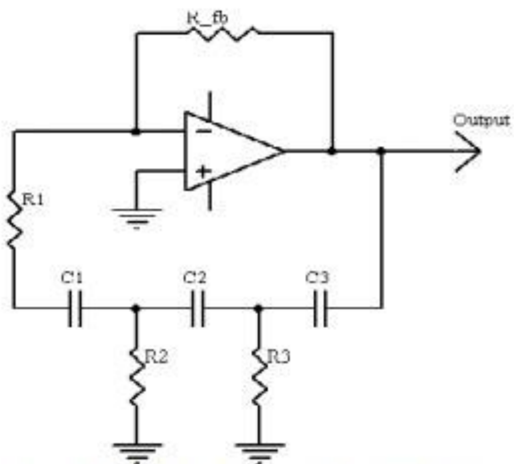

Fig.5.3 RC Phase shift oscillator

RC phase shift oscillator using op-amp in inverting amplifier introduces the phase shift of 180º between input and output. The feedback network consists of 3 RC sections each producing 60º phase shift. Such a RC phase shift oscillator using op-amp is shown in the figure.

The output of amplifier is given to feedback network. The output of feedback network drives the amplifier. The total phase shift around a loop is 1800 of amplifier and 180 due to 3 RC sections, thus 360 °. This satisfies the required condition for positive feedback and circuit works as an oscillator.

$$f_{oscillation} = \frac{1}{2\pi\sqrt{R_2R_3(C_1C_2+C_1C_3+C_2C_3)+R_1R_3(C_1C_2+C_1C_3)+R_1R_2C_1C_2}}$$

Oscillation criterion:

$$R_{feedback} = 2(R_1+R_2+R_3)+\frac{2R_1R_3}{R_2}+\frac{C_2R_2+C_2R_3+C_3R_3}{C_1}$$

$$+\frac{2C_1R_1+C_1R_2+C_3R_3}{C_2}+\frac{2C_1R_1+2C_2R_1+C_1R_2+C_2R_2+C_2R_3}{C_3}$$

$$+\frac{C_1R_1^2+C_3R_1R_3}{C_2R_2}+\frac{C_2R_1R_3+C_1R_1^2}{C_3R_2}+\frac{C_1R_1^2+C_1R_1R_2+C_2R_1R_2}{C_3R_3}$$

$$A\beta = A\left(\frac{1}{RCs+1}\right)^3 \qquad (3)$$

The loop phase shift is –180° when the phase shift of each section is –60°, and this occurs when $\omega = 2\pi f = 1.732/RC$ because the tangent 60° = 1.73. The magnitude of β at this point is $(1/2)^3$, so the gain, A, must be equal to 8 for the system gain to be equal to 1.

Wien Bridge Oscillator:

Figure 5. 3 give the Wien-bridge circuit configuration. The loop is broken at the positive input, and the return signal is calculated in Equation 2 below.

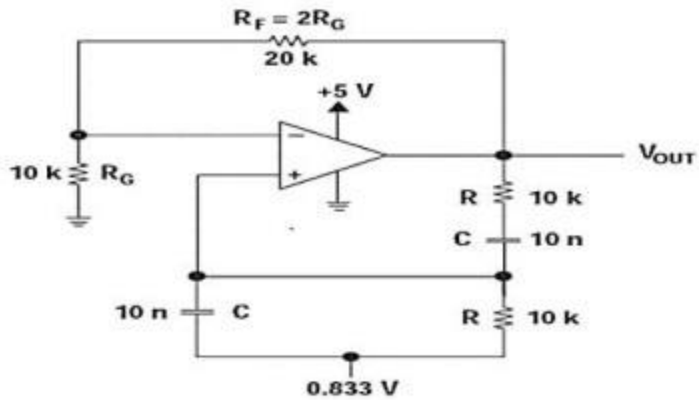

Fig.5.4 Wien Bridge Oscillator

$$\frac{V_{RETURN}}{V_{OUT}} = \frac{\frac{R}{RCs+1}}{\frac{R}{RCs+1} + R + \frac{1}{Cs}} = \frac{1}{3 + RCs + \frac{1}{RCs}} = \frac{1}{3 + j\left(RC\omega - \frac{1}{RC\omega}\right)}. \qquad (2)$$

where $s = j\omega$ and $j = \sqrt{\ 1}$.

When $\omega = 2\pi f = 1/RC$, the feedback is in phase (this is positive feedback), and the gain is 1/3, so oscillation requires an amplifier with a gain of 3. When RF = 2RG, the amplifier gain is 3 and oscillation occurs at $f = 1/2\pi RC$. The circuit oscillated at 1.65 kHz rather than 1.59 kHz with the component values shown in Figure 3, but the distortion is noticeable.

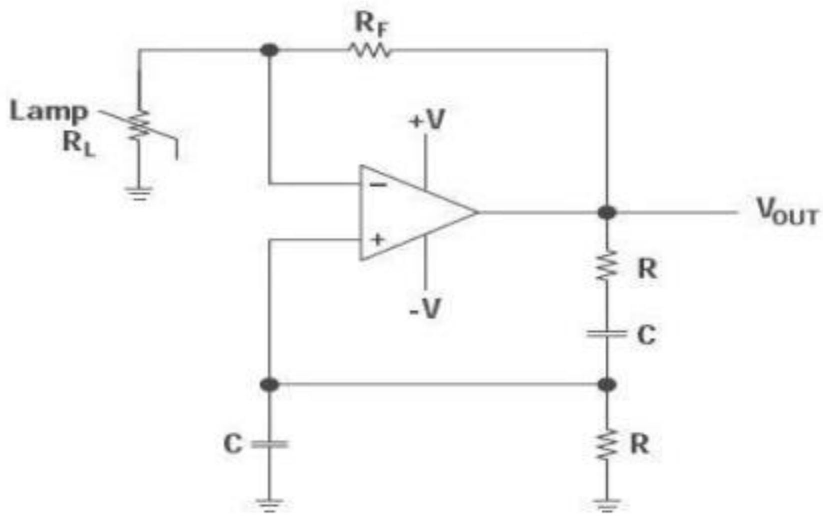

Fig.5.5 Wien Bridge Circuit Schematic with non-linear feedback

Figure 4 shows a Wien-bridge circuit with non-linear feedback. The lamp resistance, RL, is nominally selected as half the feedback resistance, RF, at the lamp current established by RF and RL. The non-linear relationship between the lamp current and resistance keeps output voltage changes small.

If a voltage source is applied directly to the input of an **ideal** amplifier with feedback, the input current will be:

$$i_{in} = \frac{v_{in} - v_{out}}{Z_f}$$

Where *vin* is the input voltage, *vout* is the output voltage, and *Zf* is the feedback impedance. If the voltage gain of the amplifier is defined as:

$$A_v = \frac{v_{out}}{v_{in}}$$

And the input admittance is defined as:

$$Y_i = \frac{i_{in}}{v_{in}}$$

Input admittance can be rewritten as:

$$Y_i \quad \frac{1 - A_v}{Z_f}$$

For the Wien Bridge, *Zf* is given by:

$$Z_f = R + \frac{1}{j\omega C}$$

$$Y_i = \frac{(1 - A_v)\left(\omega^2 C^2 R + j\omega C\right)}{1 + (\omega C R)^2}$$

If *Av* is greater than 1, the input admittance is a negative resistance in parallel with an inductance.

The inductance is:

$$L_{in} = \frac{\omega^2 C^2 R^2 + 1}{\omega^2 C\,(A_v - 1)}$$

If a capacitor with the same value of *C* is placed in parallel with the input, the circuit has a natural resonance at:

$$\omega = \frac{1}{\sqrt{L_{in} C}}$$

Substituting and solving for inductance yields:

$$L_{in} = \frac{R^2 C}{A_v - 2}$$

If Av is chosen to be 3: $Lin = R^2C$

Substituting this value yields:

$$\omega = \frac{1}{RC} \quad \text{Or} \quad f = \frac{1}{2\pi RC}$$

Similarly, the input resistance at the frequency above is:

$$R_{in} = \frac{-2R}{A_v - 1}$$

For $Av = 3$: $Rin = -R$

If a resistor is placed in parallel with the amplifier input, it will cancel some of the negative resistance. If the net resistance is negative, amplitude will grow until clipping occurs.

Similarly, if the net resistance is positive, oscillation amplitude will decay. If a resistance is added in parallel with exactly the value of R, the net resistance will be infinite and the circuit can sustain stable oscillation at any amplitude allowed by the amplifier.

Increasing the gain makes the net resistance more negative, which increases amplitude. If gain is reduced to exactly 3 when suitable amplitude is reached, stable, low distortion oscillations will result.

Amplitude stabilization circuits typically increase gain until suitable output amplitude is reached. As long as R, C, and the amplifier are linear, distortion will be minimal.

Astable Multivibrator

The two states of circuit are only stable for a limited time and the circuit switches between them with the output alternating between positive and negative saturation values.

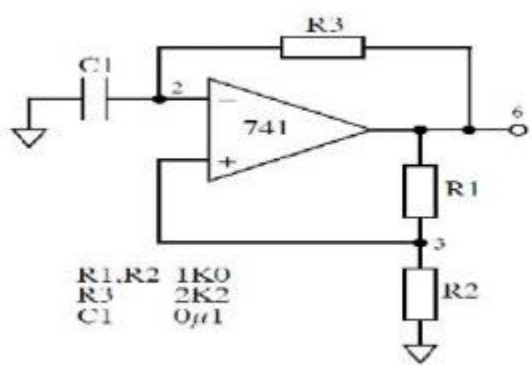

Fig. 5.6 Astable multivibrator circuit

Analysis of this circuit starts with the assumption that at time *t*=0 the output has just switched to state 1, and the transition would have occurred.

An op-amp Astable multivibrator is also called as free running oscillator. The basic principle of generation of square wave is to force an op-amp to operate in the saturation region (±Vsat).

A fraction β =R2/(R1+R2) of the output is feedback to the positive input terminal of op-amp. The charge in the capacitor increases & decreases upto a threshold value called ±βVsat. The charge in the capacitor triggers the op-amp to stay either at +Vsat or –Vsat.

Asymmetrical square wave can also be generated with the help of Zener diodes. Astable multi vibrator do not require a external trigger pulse for its operation & output toggles from one state to another and does not contain a stable state.

Astable multi vibrator is mainly used in timing applications & waveforms generators.

Design

1. The expression of fo is obtained from the charging period t1 & t2 of capacitor as T=2RCln (R1+2R2)/R1

2. To simplify the above expression, the value of R1 & R2 should be taken as R2 = 1.16R Such that fo simplifies to fo =1/2RC.

3. Assume the value of R1 and find R2.

4. Assume the value of C & Determine R from fo =1/2R C

5. Calculate the threshold point from βVSATl = R1lVTl/ R1-R2 l/βVSATl w h e r e β is the feedback ratio.

Monostable Multivibrator using Op-amp:

circuit diagram:

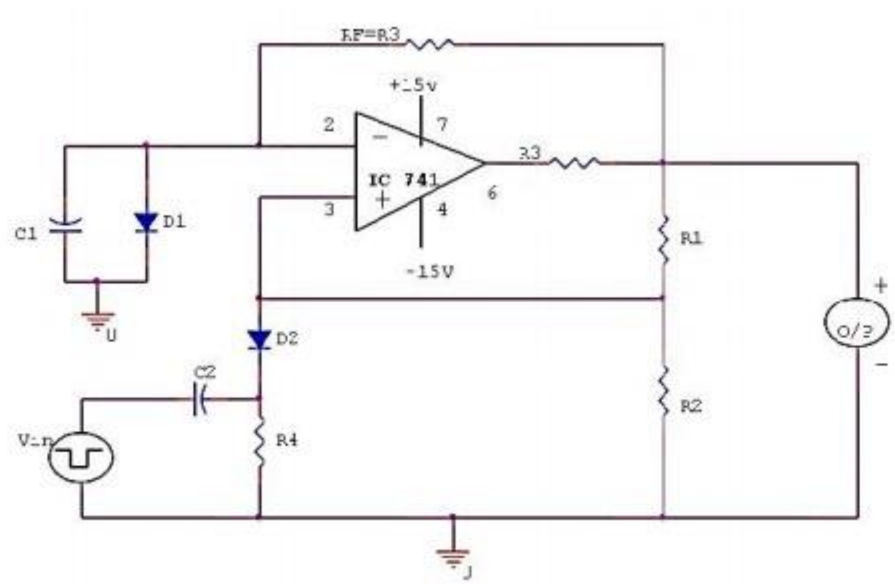

Fig.5.7 Mono stable Multi vibrator using Op-amp

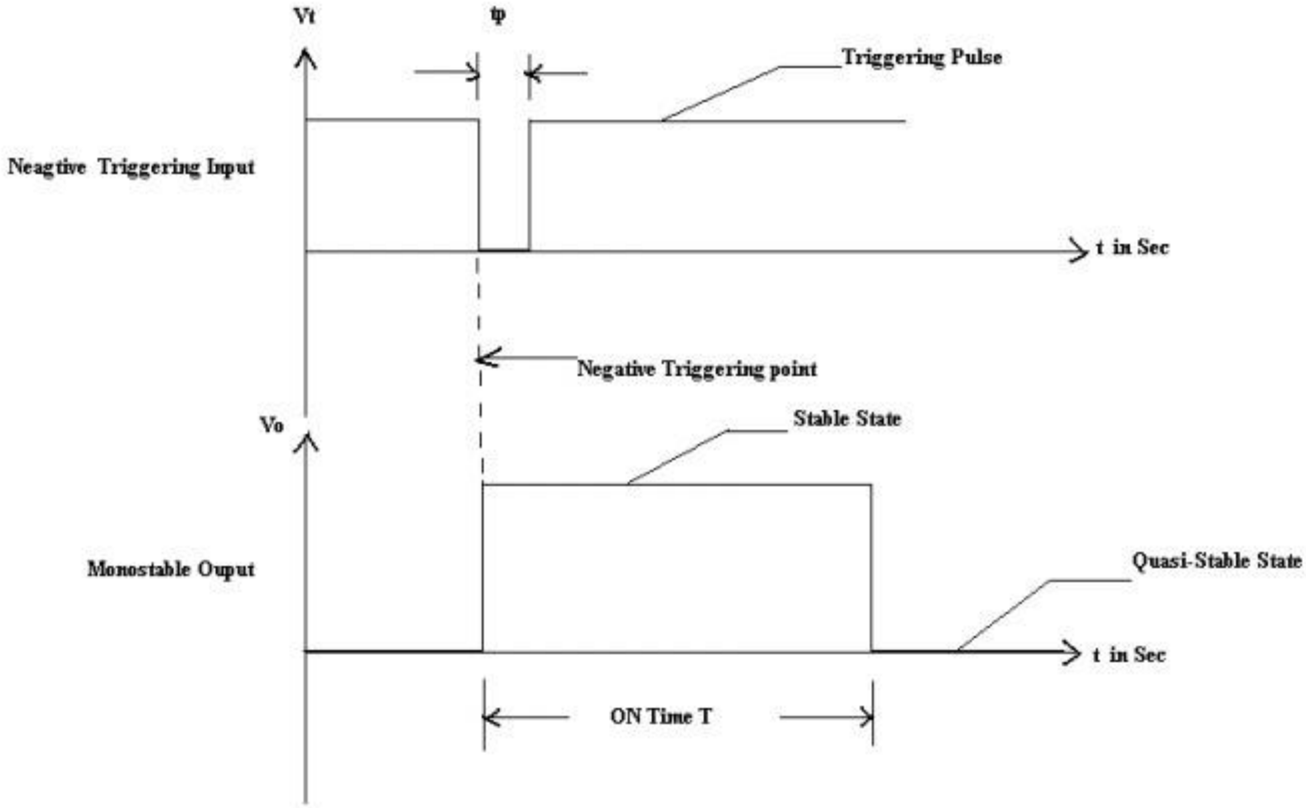

Fig.5.8 Input Output Waveform:

A multivibrator which has only one stable and the other is quasi stable state is called as Monostable multivibrator or one-short multivibrator. This circuit is useful for generating signal output pulse of adjustable time duration in response to a triggering signal. The width of the output pulse depends only on the external components connected to the op-amp. Usually a negative trigger pulse is given to make the output switch to other state. But, it then return to its stable state after a time interval determining by circuit components. The pulse width T can be given as T = 0.69RC. For Monostable operation the triggering pulse width Tp should be less then T, the pulse width of Monostable multivibrator. This circuit is also called as time delay circuit or gating circuit.

Design:

1. Calculating β from expression

$$\beta = \frac{R1}{R1 + R2}$$

2. The value of R and C from the pulse width time expression.

$$T = RC \ln \frac{(1 + V_D / V_{sat})}{1 - \beta}$$

$$T = RC \ln \frac{(1 + V_D / V_{sat})}{0.5}$$

$$T \equiv 0.69RC.$$

3. Triggering pulse width T_p must be much smaller than T. Tp < T.

Triangular Wave Generator Circuit:

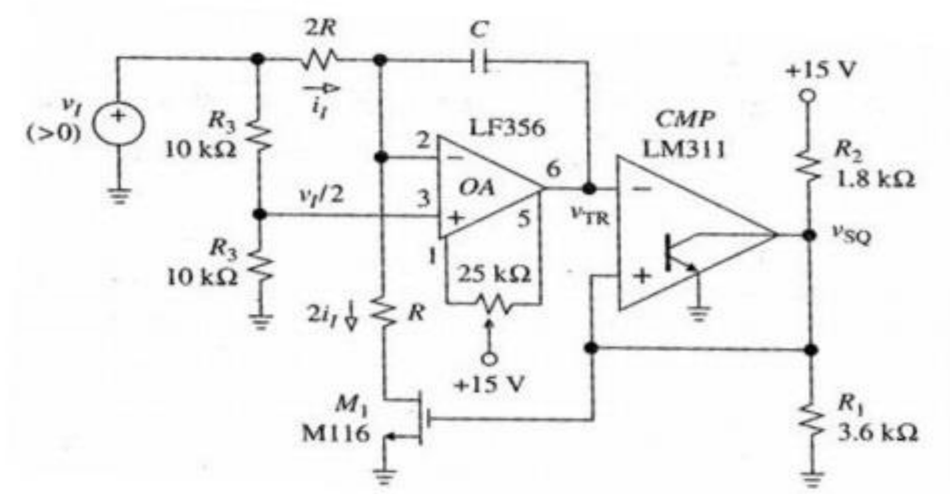

Fig. 5.9 Circuit diagram of Triangular waveform generator

This signal generator gives two waveforms: a triangle-wave and a square- wave. The central component of this circuit is the integrator capacitor CI. Basically we are interested in performing two functions on CI: *charge it, discharge it - repeat indefinitely.* The output waveforms are shown here and it is apparent that a square wave generator followed by an integrator acts as a triangular wave generator.

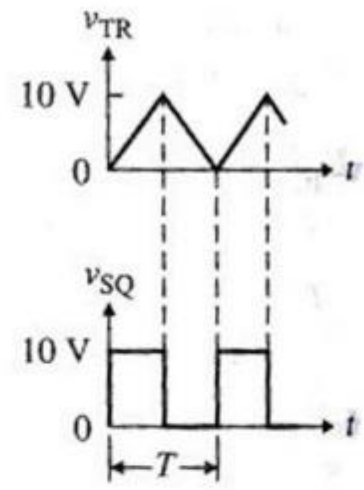

Fig.5.10 Output waveforms from generator

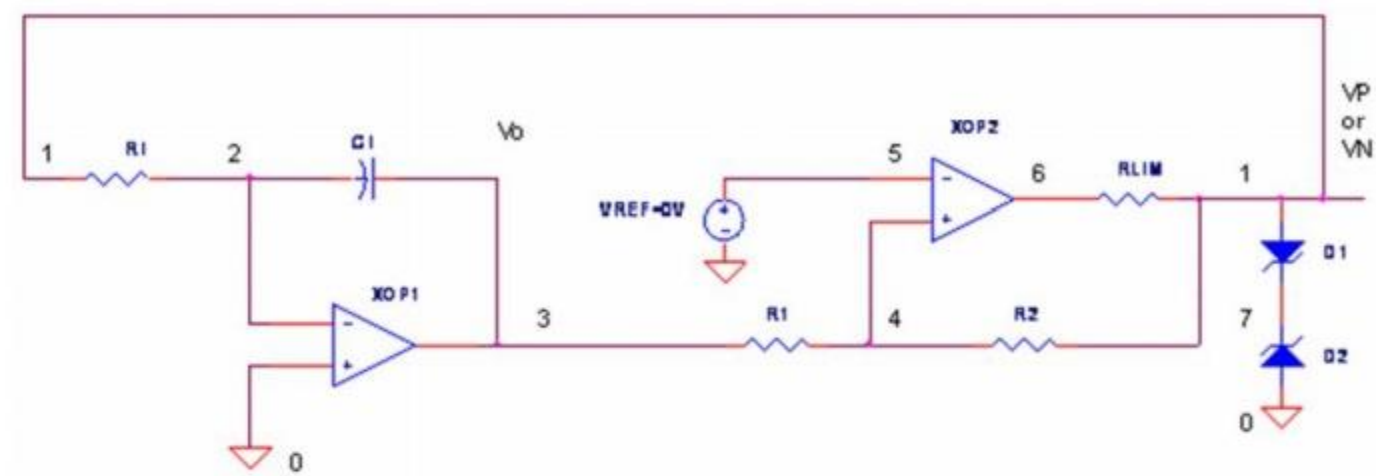

Fig. 5.11 Basic triangular waveform generator

The triangle peaks and period may not accurately meet +/-10V swing at 100 us. The main reason is that current source and thresholds are derived from Zener diodes - not exactly the most accurate reference.

Linear Ramp Generator

A triangle wave implies that the circuit generates a linear voltage ramp. One way to achieve this goal is by charging discharging CI with a constant current. The Op Amp Integrator provides for this.

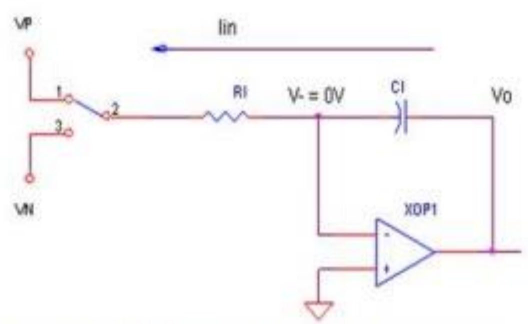

Fig. 5.12 Linear Ramp Generator

Ramp Up

Connect R_I to V_N and With V- held at the virtual ground (0V), a constant current flows from V- to V_N.

$I_{in} = V_N / R_I$.

CI integrates Iin creating a positive linear ramp at Vo. The ramp is linear because Vo changes proportionally to the time elapsed ΔT.

$\Delta Vo = - V_N / (C_I \cdot R_I) \cdot \Delta T$

Ramp Down Connect R_I to V_P and constant current flows from V_P to V-,

$I_{in} = - V_P / R_I$.

Now Vo ramps down linearly $\Delta Vo = - V_P / (C_I \cdot R_I) \cdot \Delta T$

Ramp Up: $\Delta V_o/\Delta T = -V_N/(C_I R_I)$

Ramp Down: $\Delta Vo / \Delta T = - V_P / (C_I \cdot R_I)$

These equations show the parameters available to control the ramp up / down speeds. Asymmetrical voltage swings are got by including a reference voltage VREF to the comparator's negative input.

$V_{th}+ = V_{REF} \cdot (R_1+R_2)/R_2 - V_N \cdot R_1/R_2$

$V_{th}- = V_{REF} \cdot (R_1+R_2)/R_2 - V_P \cdot R_1 / R_2$

Upper and Lower Bounds

When do we switch from charging to discharging CI? Basically, there is a need to pick two levels - *an upper and a lower threshold* - to define the bounds of the triangle wave. The circuit ramps up or down, reversing at the upper and lower thresholds.

- With one leg of RI at VN, the output **ramps up** until the **Upper Threshold (Vth+)** is reached. Then RI is switched from VN to VP.

With one leg of RI at VP, the output **ramps down** until the **Lower Threshold (Vth-)** is reached. Then RI is switched from VP to VN.

Comparator:

An Op Amp Comparator with two thresholds. Produce circuit changes in output state from VN to VP (or vice-versa) depending on the upper Vth+ and lower Vth- thresholds.

$Vth+=-V_N \cdot R_1/R_2$

$Vth- = -V_P \cdot R_1 / R_2$

Comparator Working:

- When Vin > Vth+, the output switches to VP, the POSITIVE output state.
- When Vin < Vth-, the output switches to VN, the NEGATIVE output state.

Zener diodes D1 and D2 set the positive and negative output levels:

$V_P=V_{fD1}+V_{ZD2}$ $V_N = V_{fD2} + V_{ZD1}$.

These output levels do double duty - they set the comparator thresholds, and set the voltage levels for the next stage - the integrator.