UNIT 14 ANALOG INTEGRATED CIRCUITS (SIGNAL GENERATORS)

Structure

14.1 INTRODUCTION

In the previous unit you learnt about various electronic circuits which process input signals in a desired manner to produce corresponding outputs. You will now learn about circuits which function as voltage sources having periodic output waveforms. This Unit introduces you to oscillators which produce sinusoidal output voltages and function generators which are circuits that generate a variety of waveforms such as sine wave, square wave and triangular wave needed for testing and timing in electronic systems. These circuits are found in all test oscillators, signal generators, timers and clock generators.

Objectives

After studying this unit, you should be able to

- explain how sinusoidal waveforms can be generated,
- derive the condition for oscillation and frequency of oscillation of any oscillator circuit,
- explain the working of a circuit that can show hysteresis characteristic,
- describe a regenerative comparator for generating square waveforms, and
- explain the working of precise timing indicators.

14.2 SINUSOIDAL OSCILLATORS

Sinusoidal oscillators are circuits containing either active elements like transistors and opamps and *LC* elements or the same active elements along with *RC* networks. These are respectively called *LC* oscillators and *RC* oscillators.

14.2.1 Harmonic Oscillator

Mathematically, it is known that a second order differential equation with constant coefficients

$$\frac{d^2 v}{d t^2} + \alpha \frac{d v}{d t} + \beta v = 0$$

has a solution, $v = V_p\, e^{-\frac{\alpha t}{2}} \sin\left(\sqrt{\beta - \frac{\alpha^2}{4}}\, t + \phi\right)$. We have

Case 1, α positive indicates that the sinusoidal oscillation occurring at a radian frequency $w = \sqrt{\beta - \alpha^2/4}$ decays exponentially.

Case 2, $\alpha = 0$, $w = \sqrt{\beta}$, the sinusoidal oscillation is sustained at a constant amplitude.

Case 3, α negative indicates that the amplitude of oscillation is growing exponentially.

14.2.2 *LC* - Oscillators

A simple circuit to simulate the foregoing equation is the *LC* parallel resonant circuit (known as tank circuit). Energy once put in it is available as sinusoidal oscillation at constant amplitude changing the nature of its storage continuously from capacitive to inductive and back again.

If the capacitor and inductor loss component is represented by a parallel resistance R_p across L and C, then the α component exists. Therefore, damped oscillations results every time energy is pumped into it. In order to cancel the loss component a negative resistance, $-R_p'$ must be connected across the *LC* circuit as shown in Figure 14.1.

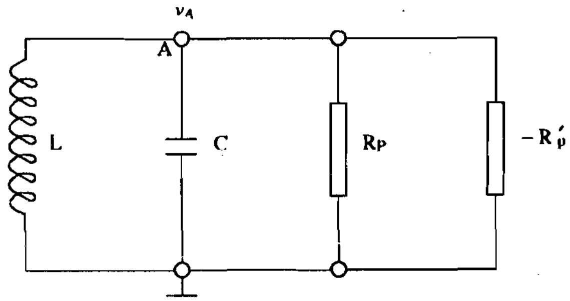

Figure 14.1 : *LC* oscillator

Equating the sum of currents at node A to 0,

$$C\frac{d v_A}{d t} + \frac{1}{L}\int v_A \, d t + \frac{v_A}{R_p} - \frac{v_A}{R_p'} = 0$$

$$\frac{d^2 v_A}{d t} + \frac{1}{C}\left(\frac{1}{R_p} - \frac{1}{R_p'}\right)\frac{d v_A}{d t} + \frac{v_A}{L C} = 0$$

We have :

(i) Condition for oscillations : $R_p = R_p'$; Frequency of oscillation, $w = \frac{1}{\sqrt{L C}}$; Constant amplitude oscillations occur.

(ii) If $R_p < R_p'$ exponentially decaying output results.

(iii) If $R_p > R_p'$ exponentially growing output results.

Using the concept of admittance, the net admittance of the parallel circuit is

$$\overline{Y}_{net} = j\left(w C - \frac{1}{w L}\right) + \frac{1}{R_p} - \frac{1}{R_p'}$$

If $\overline{Y}_{net}$ is zero for any frequency then a voltage at that frequency can exist across the parallel circuit without any external current source connected to it, i.e. if the net admittance between two points in a circuit becomes zero at a single frequency then the circuit is a sinusoidal oscillator.

Example 14.1

In Figure 14.1 if $L = 1$ mH, $C = 1$ nF and $R_p = 100$ kΩ, determine the frequency of oscillation and the value of R_p' needed.

Solution

$$w_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10^{-3} \times 10^{-9}}} = 10^6 \text{ rad / sec}$$

$$f_0 = \frac{10^6}{2\pi} \text{ Hz} = 159.2 \text{ kHz}$$

$$R_p' = 100 \text{ k}\Omega$$

SAQ 1

Design a tank circuit to oscillate at $f_0 = 100$ kHz using $C = 1$ nF. The loss component of the tank circuit can be represented by a shunt resistor of magnitude 200 kΩ.

14.2.3 *RC* Oscillator

The *LC* oscillator of Figure 14.1 can be converted into an *RC* oscillator simply by replacing the inductor and the negative resistance by simulated inductor and negative resistance.

A Negative Resistance Simulator

Consider an amplifier (non-inverting) with a gain of two.

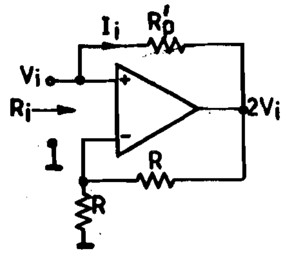

Figure 14.2 : Negative resistance simulator

If a resistance R_p' is now connected between the input and the output of this amplifier as shown in Figure 14.2, let the input resistance seen by the signal v_i be R_i.

$$i_i = \frac{v_i - 2v_i}{R_p'} \quad \text{or}$$

$$R_i = \frac{v_i}{i_i} = -R_p'.$$

An Inductor Simulator

Consider the circuit shown in Figure 14.3, using two opamps. Its input impedance $\frac{\bar{V}_i}{\bar{I}_i}$ can be evaluated as follows :

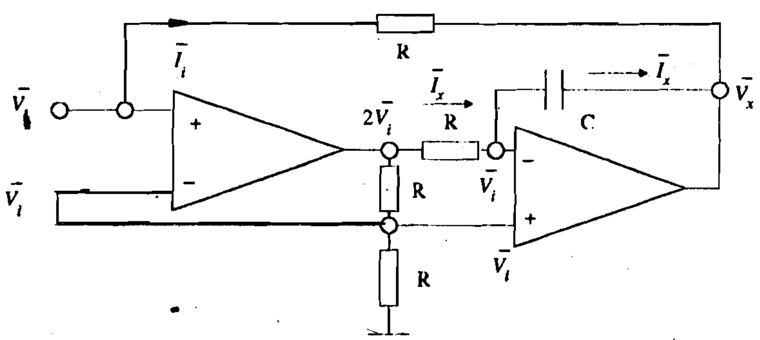

Figure 14.3 : Inductor Simulator Circuit

$$\bar{I}_x = \frac{2\bar{V}_i - \bar{V}_i}{R} = \frac{\bar{V}_i}{R}$$

$$\bar{V}_x = \bar{V}_i - \frac{\bar{V}_i}{jwCR}$$

$$\bar{I}_i = \frac{\bar{V}_i - \left(\bar{V}_i - \frac{\bar{V}_i}{jwCR}\right)}{R}$$

$$\bar{I}_i = \frac{\bar{V}_i}{jwCR^2} = \frac{\bar{V}_i}{jwL},$$

where $L = CR^2$

$$\bar{Z}_i = \frac{\bar{V}_i}{\bar{I}_i} = jwCR^2$$

The circuit simulates therefore an inductor $L = CR^2$ between input terminal and ground. This property was referred to, while discussing inductance simulation in Section 13.2.7.

RC Oscillator

A combination of inductor simulator and capacitor along with negative resistance simulator

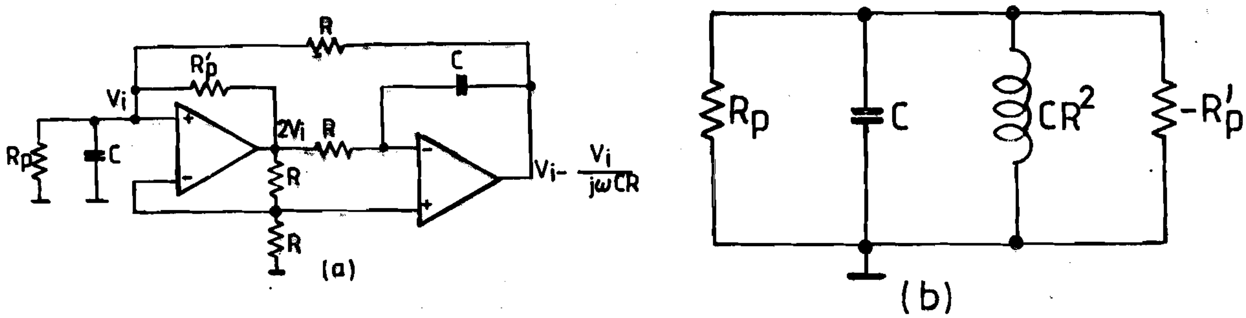

Figure 14.4 : (a) *RC* Oscillator (b) Simulated admittance of the *RC* Oscillator

for compensating for the losses R_p, shown in Figure 14.4 is an oscillator.

It becomes a sinusoidal oscillator if $R_p' = R_p$ and the frequency of oscillation would be

$$w = \frac{1}{\sqrt{LC}}, \text{ where } L = CR^2$$

Therefore,

$$w = \frac{1}{\sqrt{R^2 C^2}} = \frac{1}{RC}$$

Example 14.2

Simulate an inductor of $L = 1$ mH using opamps, resistors and capacitors.

Solution

The circuit is as shown in Figure 14.3. We take $C = 1$ n F. $L = 1$ mH.

$$L = CR^2, \quad R = \left(\frac{L}{C}\right)^{1/2} = \left(\frac{10^{-3}}{10^{-9}}\right)^{1/2} = 1 \text{ k}\Omega$$

SAQ 2

Simulate an inductor of magnitude 20 mH using opamps, resistors and capacitors.

Example 14.3

Simulate a negative resistance of 200 kΩ.

Solution

The circuit to simulate negative resistance is as shown in Figure 14.2 with $R_p' = 200$ kΩ. R can be 10 kΩ.

Then $R_i = -200$ kΩ.

SAQ 3

Design an oscillator circuit to oscillate at 50 kHz using only resistors, capacitors and opamps.

14.2.4 Quadrature Oscillator

The problem of oscillator synthesis can be thought of also as simulation of the harmonic oscillator equation viz.,

$$\alpha \frac{d^2 v}{d t^2} + \beta v = 0 .$$

The solution of this equation is

$$v = V_p \sin\left(\sqrt{\frac{\beta}{\alpha}}\, t + \theta \right) = V_p \sin (wt + \theta),$$

where $w = \sqrt{\frac{\beta}{\alpha}}$.

The same equation can be rewritten as

$$\alpha \frac{d^2 v}{d t^2} = -\beta v$$

Assuming that $\alpha \frac{d^2 v}{d t^2}$ of the LHS of the equation is available, one can get $\frac{d v}{d t}$ and v by using integrators in succession as shown in Figure 14.5. An inverter makes the output to be

$$\frac{-\alpha}{R^2 C^2} v$$

the desired form in the equation on the RHS. Therefore, the connection of the output to the input solves the equation,

$$\frac{d^2 v}{dt^2} + \frac{1}{R^2 C^2} v = 0,$$

whose solution is $v = V_p \sin (\frac{t}{RC} + \theta)$

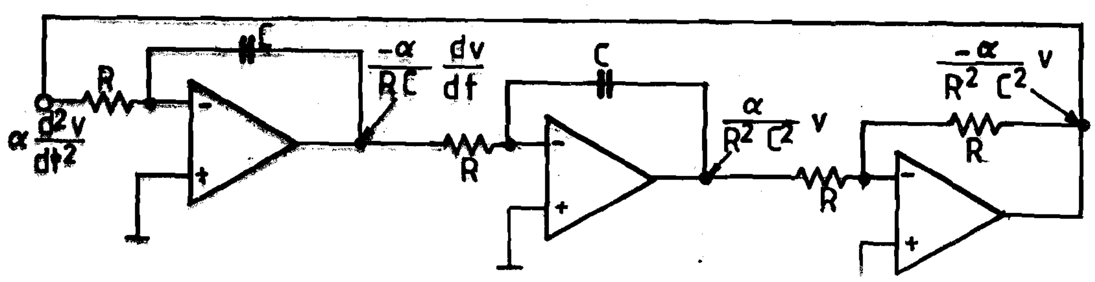

Figure 14.5 : Quadrature Oscillator

This circuit is called *Double Integrator Oscillator* or *Quadrature Oscillator*. It has two outputs which are in phase quadrature (i.e. with a phase difference of 90°) at the outputs of the two integrators.

Example 14.4

For the double-integrator oscillator shown in Figure 14.5, $R = 1$ kΩ and $C = 0.1$ μ F. Determine the frequency of oscillation.

Solution

$$w = \frac{1}{RC} = \frac{1}{10^3 \times 10^{-7}} = 10^4 \text{ rad / sec}$$

$$f = 1.591 \text{ kHz}$$

SAQ 4

Design a quadrature oscillator for oscillation frequency of 1 kHz.

14.2.5 Wien Bridge Oscillator

The Wien Bridge is the circuit shown as a bridge network in Figure 14.6. When the operational amplifier gets embedded in the bridge *RC* network it becomes an oscillator. This is a very popular form of *RC* oscillator.

Applying Kirchoff's laws, $i = \frac{v}{R} + C\frac{dv}{dt}$

$$iR + \frac{1}{C}\int i\,dt + v = \left(1 + \frac{R_2}{R_1}\right)v.$$

Combining the above two equations,

$$\frac{d^2 v}{dt^2} + \frac{1}{RC}\frac{dv}{dt}\left(2 - \frac{R_2}{R_1}\right) + \frac{v}{R^2 C^2} = 0.$$

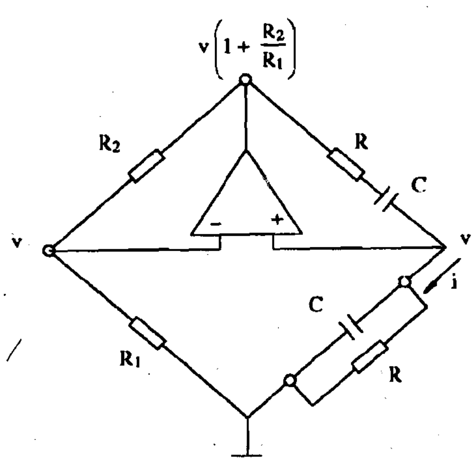

Figure 14.6 : Wien Bridge Oscillator

The condition for oscillation becomes : $2 = \frac{R_2}{R_1}$

The resulting frequency of oscillation $w = \frac{1}{RC}$

Example 14.5

Design a Wien bridge oscillator for a frequency of 1 kHz.

Solution

The circuit is as shown in Figure 14.6.

Let $R_1 = 1\ k\Omega$.

$\frac{R_2}{R_1} = 2$.

Therefore $R_2 = 2\ k\Omega$.

$w = \frac{1}{RC} = 2\pi \times 10^3$.

For $R = 1\ k\Omega$, $C = \frac{1}{2\pi \times 10^3 \times 10^3}$ F = 0.1591 μF.

SAQ 5

Design a Wien bridge oscillator for a frequency of 100 kHz.

14.2.6 Phase Shift Oscillator

This is another form of *RC* oscillator, in which an *RC* ladder network is used to generate the necessary phase shift for the feedback signal required to produce sustained oscillations. The circuit is shown in Figure 14.7. Let us now analyse this circuit. If v is the node voltage marked in the circuit, the current through the input resistor *R* of the amplifier is v/R. This is also the current through the last capacitor *C*.

Voltage at node 2 $= v + \frac{1}{C} \int \frac{v}{R}\, dt$

Current in *C* between nodes 1 and 2 $= 2\frac{v}{R} + \frac{1}{CR^2} \int v\, dt$

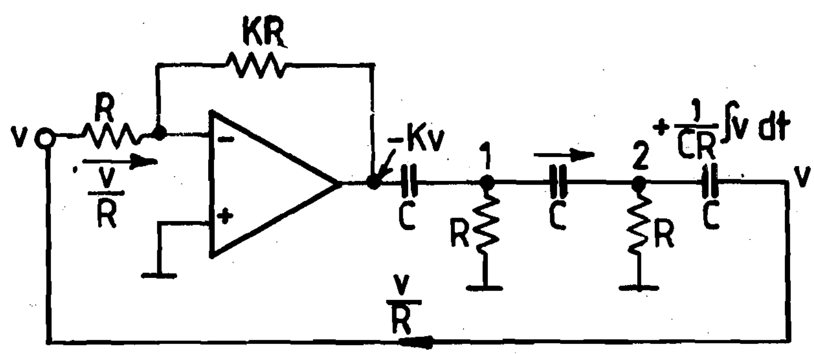

Figure 14.7 : Phase Shift Oscillator

* To simplify notation, the differential *dt* is not repeated in the multiple integrals.

Voltage at the node 1 = $v + \frac{3}{RC} \int v\,dt + \frac{1}{C^2 R^2} \int\int v\,dt$ *

Current from the opamp to node 1 = $\frac{3v}{R} + \frac{4}{CR^2} \int v\,dt + \frac{1}{C^2 R^3} \int\int v\,dt$

Hence,

$$-Kv = v + \frac{6}{CR} \int v\,dt + \frac{5}{C^2 R^2} \int\int v\,dt + \frac{1}{C^3 R^3} \int\int\int v\,dt$$

or

$$0 = (1+K)\,v + \frac{6}{CR} \int v\,dt + \frac{5}{C^2 R^2} \int\int v\,dt + \frac{1}{C^3 R^3} \int\int\int v\,dt$$

If v is a sinusoid, then the first and third terms on the right hand side have the same phase (or 180° phase difference), while the second and fourth terms have a quadrature phase ($\pm$ 90°). Since the above equation is to be satified for all t, the two groups of terms on the right hand side should separately add up to zero.

Therefore,

$$(1+K)\,v + \frac{5}{C^2 R^2} \int\int v\,dt = 0 \quad \text{and} \quad \frac{6}{CR} \int v\,dt + \int\int\int \frac{v\,dt}{C^3 R^3} = 0$$

The two equations yield respectively

$$\frac{d^2v}{dt^2} + \frac{5}{C^2R^2(1+K)}v = 0 \quad \text{and} \quad \frac{d^2v}{dt^2} + \frac{1}{6C^2R^2}v = 0$$

From the above two equations,

$$w = \frac{1}{\sqrt{6}\,RC} = \frac{\sqrt{5}}{\sqrt{(1+K)}\,RC}$$

Thus,

$$K = 29.$$

See Example 3.25 of Unit 3 for an alternative derivation of the result.

Example 14.6

Design a phase-shift oscillator for a frequency of 10 kHz.

Solution

The circuit is as shown in Figure 14.7.

With $R = 1\ \text{k}\Omega$,

$KR = 29\ \text{k}\Omega$,

and $w = \frac{1}{\sqrt{6}\,RC} = \frac{1}{\sqrt{6} \times 10^3 \times C} = 2\pi \times 10^4$

$$C = \frac{1}{\sqrt{6} \times 10^7 \times 2\pi}\ \text{F} = 6.49\ \text{nF}$$

SAQ 6

Design a phase shift oscillator for a frequency of 12 kHz.

14.3 NON-SINUSOIDAL OSCILLATORS

Non-sinusoidal oscillators generate primarily square, triangular, rectangular and saw tooth waveforms. The triangular waveform can then be transformed into a sinusoidal waveform, where required, using nonlinear circuits.

14.3.1 Comparator

A comparator is a circuit that compares two voltages or currents. It indicates at its output when the two quantities compared become equal. A high gain amplifier or an operational amplifier can be used as a comparator. The input/output characteristic of the amplifier shown in Figure 14.8 (a) is indicated in Figure 14.8 (b).

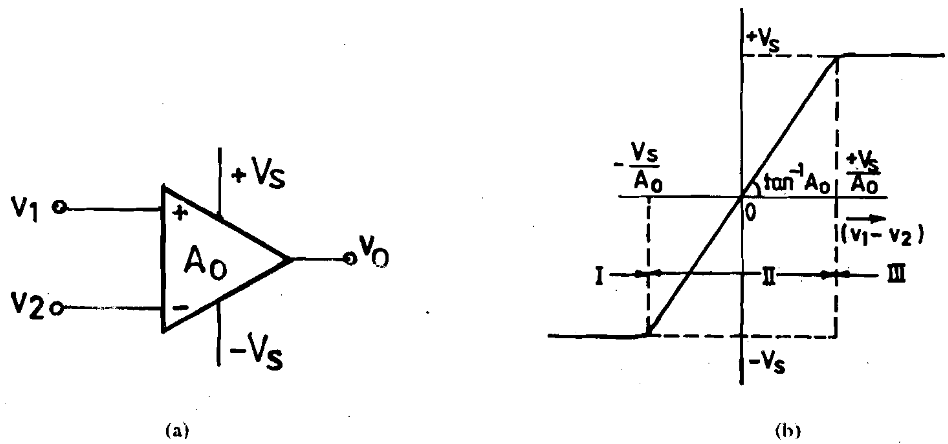

Figure 14.8 : (a) Operational Amplifier comparator (b) Input/Output characteristic of the opamp.

There are three distinct regions in the characteristic : Region I where $(V_I - V_2)$ is less than $-V_s/A_0$, the output is at $-V_S$. Region II where $(V_I - V_2)$ lies between $-V_S/A_0$ and $+V_S/A_0$ and the output lies between $-V_S$ and $+V_S$. Region III where $(V_I - V_2)$ is greater than V_S/A_0 and the output is $+V_S$. If $A_0 \to \infty$ the region of uncertainty tends to zero and the error in comparison also tends to zero. The three regions are characterised by

I $\quad V_2 > V_1 ;\ V_0 = -V_S$

II $\quad |V_1 - V_2| < \frac{V_S}{A_0};\ -V_S < V_0 < V_S$

III $\quad V_1 > V_2 :\ V_0 = V_S$

If $v_1 = V_p \sin wt$ and $v_2 = 0$, the output v_0 is shown in Figure 14.9.

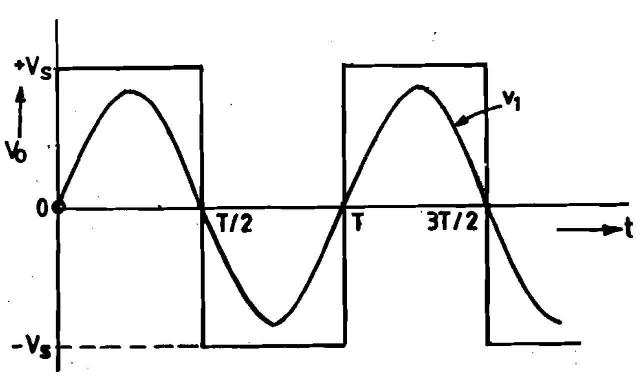

Figure 14.9 : Output waveform of the comparator for a sine wave input

14.3.2 Regenerative Comparator/Schmitt Trigger

Consider the opamp of Figure 14.8 (a) being used with positive feedback through an attenuator $\frac{R_1}{R_1 + R_2} = \beta$ connected from the output as shown in Figure 14.10 (a).

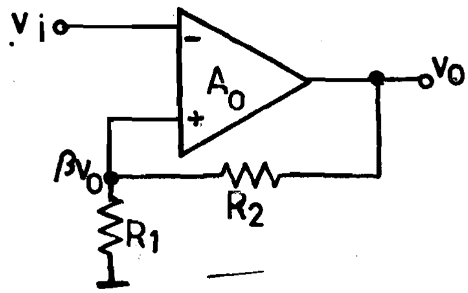

Figure 14.10 (a) : Schmitt Trigger

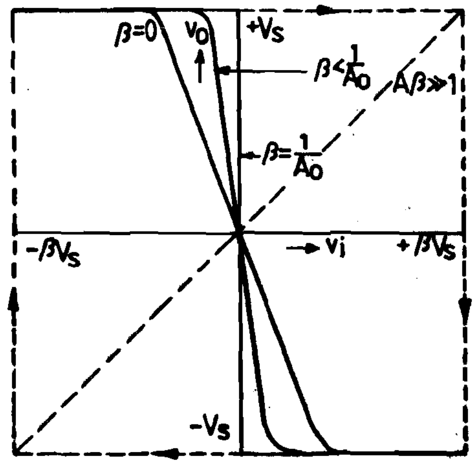

Figure 14.10 (b) : Input - Output caracteristic of the Schmitt Trigger

$$A_0\left(\beta\, v_0 - v_i\right) = v_0.$$

Therefore, $$\frac{v_0}{v_i} = \frac{-A_0}{1 - A_0\,\beta}$$

The v_0 vs v_i characteristic for this circuit is shown in Figure 14.10 (b). The slope of the characteristic is $\frac{-A_0}{\left(1 - A_0\,\beta\right)}$. It starts with $-A_0$ for $\beta = 0$ and keeps increasing as β increases. When $\beta = \frac{1}{A_0}$ it becomes infinity. It means that using a practical amplifier with finite gain one can design an ideal comparator with $\frac{v_0}{v_i} = \infty$. But such a comparator which can be used as a zero crossing detector will have uncertainty in the output when $v_i = 0$. In order to get rid of this uncertainty and make sure that the output voltage can only remain at either of the two states $+V_S$ or $-V_S$, β is made greater than $1/A_0$. This condition is known as regenerative feedback. This kind of feedback prevents the output from remaining anywhere in between $+V_S$ and $-V_S$.

The circuit under regenerative feedback situation i.e. $A_0\,\beta > 1$ can be explained as follows :

Consider $v_i = 0$. If a small disturbance in the form of noise voltage appears at the input and if it is positive the output will become a large negative value and $-A_0\,\beta$ times the input appears at the non-inverting terminal. If $A_0\,\beta > 1$ then it helps the initial disturbance in further making the output become a larger negative voltage than before and ultimately the output goes to $-V_S$. Had the initial disturbance been negative the output would have gone towards $+V_S$. That is why this circuit has only two stable states $+V_S$ and $-V_S$ and the output cannot remain anywhere in between these two states. This then becomes suitable as a good comparator circuit. This is the regenerative comparator or Schmitt trigger.

The input/output characteristic of the Schmitt trigger can be explained in the following manner. When the input voltage v_i is considerably negative the output must be at $+V_S$. The non- inverting terminal of the comparator is then at $+\beta\,V_S$. When v_i comes close to βV_S there occurs regenerative feedback and the output changes from $+V_S$ to $-V_S$. As v_i further increases V_0 remains at $-V_S$. If now the input is slowly reduced, output will remain at $-V_S$ until v_i comes close to $-\beta V_S$ and once again there occurs regenerative feedback and output changes from $-V_S$ to $+V_S$. This is shown in Figure 14.10 (b). This is known as hysteresis. The amplifier/comparator *remembers* whether the input is increasing or decreasing and accordingly changes state at $+\beta\,V_S$ or $-\beta\,V_S$. In other words there is *memory* in the circuit.

If instead of feeding the input to the inverting terminal as in Figure 14.10(a), the inverting terminal is grounded and input applied to the end of R_1, which was earlier grounded, there results another type of Schmitt trigger shown in Figure 14.10(c). Its characteristic is shown in Figure 14.10(d).

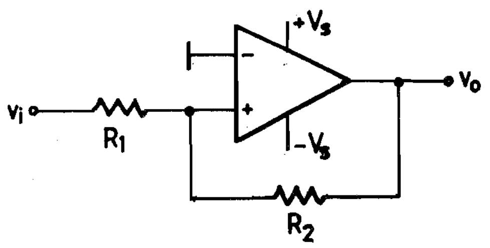

Figure 14.10(c) : Alternative circuit of a Schmitt trigger

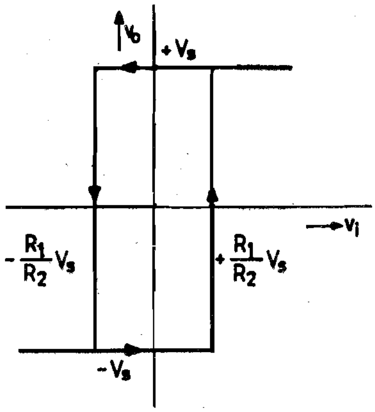

Figure 14.10(d) : Input-Output Characteristic of circuit of Figure 14.10(c)

If a sinusoidal input $v_i = V_p \sin wt$ is now applied to a comparator of Figure 14.10(a) with regenerative feedback the output would be the square wave with a peak value of V_S as shown in Figure 14.11.

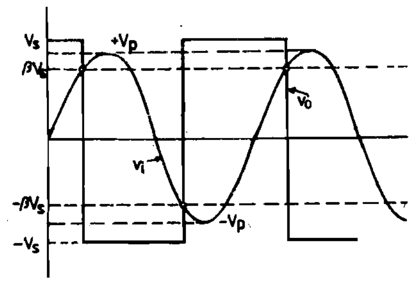

Figure 14.11 : Output of a Schmitt trigger with a sinusoidal input

The difference in the output of regenerative circuits of this section and the output of the circuit of Figure 14.8 is that $\frac{d\,v_0}{d\,t}$ in the present circuits is dependent only on the capability of the output to change from $-V_S$ to $+V_S$ or from $+V_S$ to $-V_S$ whereas $\frac{d\,v_0}{d\,t}$ in Figure 14.8 at zero crossover depends on $\frac{d\,v_i}{d\,t}$ and is $A_0\left(\frac{d\,v_i}{d\,t}\right)$.

14.3.3 Astable Multivibrator

An astable multivibrator belongs to the class of oscillators known as relaxation oscillators. It provides a square wave output in contrast to the sinusoidal oscillators which we studied in Section 14.2. As its name implies, an astable multivibrator has no stable state. It can not remain in any one state undisturbed. It keeps shifting from one state to the other. The circuit arrangement uses the Schmitt trigger with an RC-network as shown in Figure 14.12 (a). In this circuit, the amplifier is driven to positive and negative saturation during successive half cycles, thereby producing an output square wave of amplitude V_S.

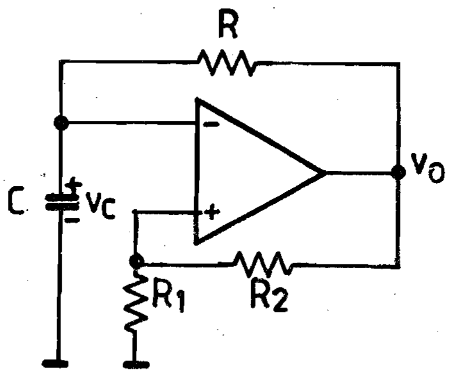

Figure 14.12 (a) : Astable Multivibrator

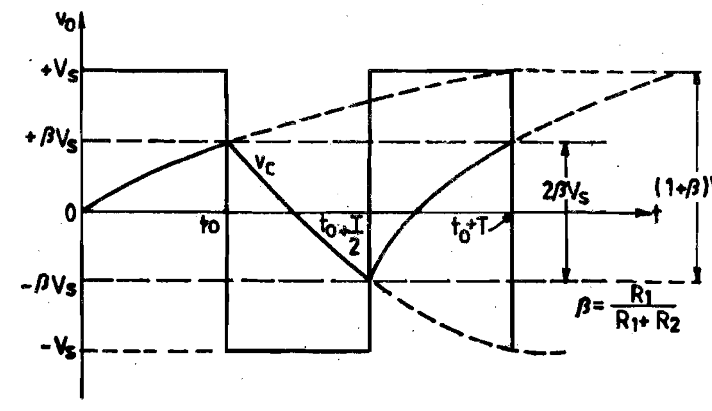

Figure 14.12 (b) : Output Waveforms of the Astable Multivibrator

At $t = 0$ consider that the output of the Schmitt trigger is at $+ V_S$. The non-inverting terminal voltage is equal to $+ \beta V_S$ (where $\beta = \frac{R_1}{R_1 + R_2}$). The capacitor C (if uncharged at $t = 0$) will now get charged at a time constant of RC. The moment the voltage across the capacitor exceeds $+ \beta V_S$ the output v_0 switches from $+ V_S$ to $- V_S$. The capacitor now starts discharging at a time constant of RC. Again the moment the voltage becomes more negative than $- \beta V_S$ the output switches to $- V_S$ from $+ V_S$. This switching continues periodically.

The period T of switching waveform can be evaluated as follows. The time taken for charging the capacitor from $- \beta V_S$ to $+ \beta V_S$ is the same as that taken for discharging it from $+ \beta V_S$ to $- \beta V_S$ and is equal to $T/2$. Thus as can be seen from Figure 14.12(b), the exponentially rising curve (with a time constant RC) starting at $t_0 + T/2$ rises by $(1 + \beta)V_S$ as $t \to \infty$, but increases by $2\beta V_S$ in a time interval $T/2$.

Hence,

$$\left(1 - \exp\left(-\frac{T}{2RC}\right)\right)(1 + \beta)\ V_S = 2\,\beta\ V_S$$

Therefore,

$$\frac{T}{2} = RC\ \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$f_0 = \frac{1}{T} = \frac{1}{2\,RC\ \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

You would observe that a square wave output at the above frequency becomes available at the output of the opamp in Figure 14.12 (a).

Example 14.7

Design an astable multivibrator for a frequency of oscillation of 1 kHz.

Solution

The circuit is as shown in Figure 14.12(a).

$$f_0 = 10^3 = \frac{1}{2\,RC\ \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

Let $\beta = \frac{1}{2}$, $R_1 = 1\ \text{k}\Omega$ and $R_2 = 1\ \text{k}\Omega$

$R = 1\ \text{k}\Omega$

$$C = \frac{1}{10^3 \times 2 \times 10^3\ \ln 3}\ \text{F} = 0.4551\ \mu\ \text{F}.$$

SAQ 7

For an astable multivibrator with $R = 1\ \text{k}\Omega$, $C = 0.1\ \mu$ F, $R_1 = R_2 = 1\ \text{k}\Omega$, determine the frequency of oscillation.

14.3.4 Monostable Multivibrator/Timer

A monostable circuit is one with only one stable state. When triggered it can go to the other state and remain there for a time duration T_0 after which it will come back to the stable state. Such a circuit is also called **Timer** circuit. Figure 14.13 (a) shows the arrangement to convert the astable circuit of Figure 14.12 (a) to be monostable by using a diode across the capacitor.

Introduction of a diode across C results in the output v_0 remaining at V_S the stable state. The voltage at the positive terminal is $R_1\ V_S / R_1 + R_2$. Voltage of the negative terminal is nearly

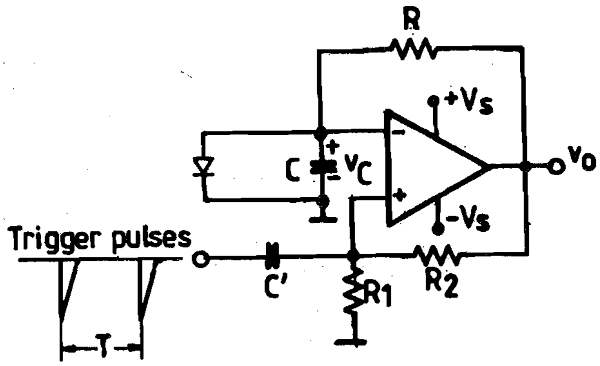

Figure 14.13 (a) : Monostable Multivibrator

zero because of the forward biased diode. The output continues to remain at + V_S. A negative trigger pulse can be applied momentarily to the non-inverting terminal through the coupling capacitor C'. This pulse can make the output v_0 to change over to $- V_S$ at the moment of its application. Then the diode gets reverse biased because the voltage across the capacitor becomes increasingly more negative with respect to time. The non-inverting terminal is now at $- V_S \left(\frac{R_1}{R_1 + R_2} \right)$ and the voltage across the capacitor approaches $- V_S$ with a time constant of RC. This is depicted pictorially in Figure 14.13 (b).

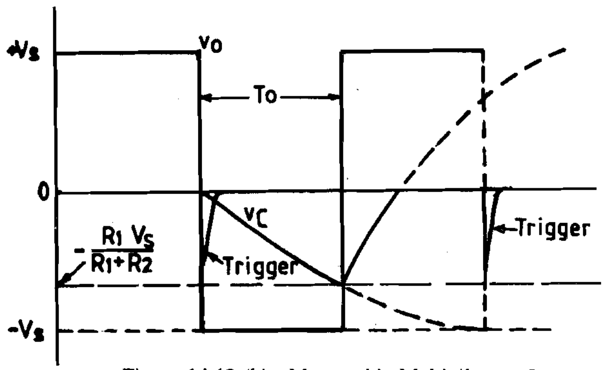

Figure 14.13 (b) : Monostable Multivibrator Output

The moment the voltage across the capacitor becomes more negative than that at the non-inverting terminal the output goes back to the stable state + V_S. The voltage across the capacitor now increases with the same time constant RC with which it was decreasing and becomes zero. Beyond this point the diode gets forward biased and keeps the voltage across the capacitor at zero thereafter. The pulse width T_0 for which the output voltage remains at $- V_S$ can be evaluated as follows :

$$- \left(\frac{R_1}{R_1 + R_2} \right) V_S = - V_S \left(1 - \exp \left(- \frac{T_0}{RC} \right) \right)$$

$$T_0 = RC \ \ln \left(1 + \frac{R_1}{R_2} \right)$$

Example 14.8

Design a monostable multivibrator for generating a pulse width of 1 μ sec after the appearance of a trigger pulse.

Solution

The circuit is as shown in Figure 14.13(a).

$$T_0 = 10^{-6} = RC \ \ln \left(1 + \frac{R_1}{R_2} \right)$$

With $R_1 = R_2 = R = 1 \text{ k}\Omega$, $\quad C = \frac{10^{-6}}{10^3 \ln 2} \text{ F} = 1.443 \text{ nF}$

SAQ 8

A monostable multivibrator with $R_1 = R_2 = R = 10$ kΩ and $C = 0.01$ μ F is used to generate a pulse of constant width after the trigger pulse is applied. Estimate the pulse width.

14.3.5 Function Generator

This circuit is made up of a Schmitt trigger (regenerative comparator) with an integrator in a loop as shown in Figure 14.14 (a).

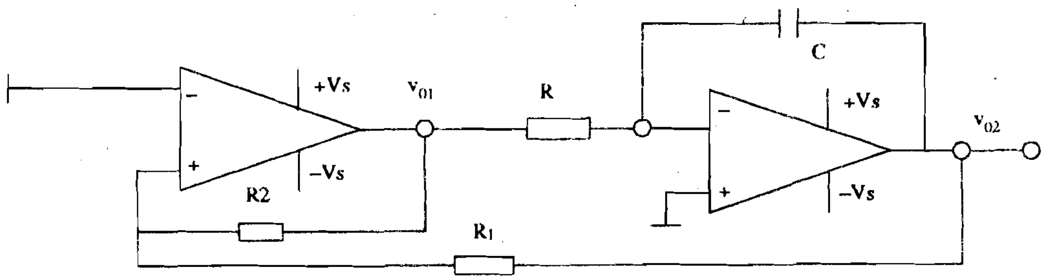

Figure 14.14 (a) : Function Generator Circuit

Let the outputs of the Schmitt trigger and integrator be designated as v_{01} and v_{02} respectively. Let us first assume that the voltage at the noninverting terminal of the first opamp is positive and accordingly that $v_{01} = V_S$. This voltage drives a charging current V_S / R through C, thereby reducing the output voltage v_{02} at a steady rate of $\frac{V_S}{RC}$ V/s. This continues till the voltage at the positive input terminal of the Schmitt trigger opamp just reaches a negative value. Through the use of superposition principle, it can be shown that this voltage equals $(R_1/R_1 + R_2)v_{01} + (R_2/R_1 + R_2)v_{02}$. Change of state of the Schmitt trigger therefore occurs when

$$\frac{v_{01}\, R_1}{R_1 + R_2} + \frac{v_{02}\, R_2}{R_1 + R_2} = 0$$

i.e, when $v_{02} = -\frac{R_1}{R_2} V_S$.

v_{01} now becomes $-V_S$ and the capacitor starts discharging, thereby increasing the voltage v_{02} linearly. The integrator charging current is $\frac{V_S}{R}$ and the rate of increase of V_{02} is $\frac{V_S}{RC}$.

The time of charging is the same as the time of discharging because the rate of charging and discharging are the same and the limits of charging and discharging are the same. The process of charging and discharging continue with a time period T.

$$\frac{V_S}{R\,C}\left(\frac{T}{2}\right) = \frac{2\,R_1}{R_2}\,V_S$$

$$\text{Time period, } T = 4\,R\,C\,\frac{R_1}{R_2}$$

$$\text{Frequency of oscillation } f = \frac{R_2}{4\,R\,C\,R_1}$$

Note that we have, simultaneously, two waveforms at this frequency, one a symmetrical square wave of amplitude V_S at the output of the Schmitt trigger, the second a symmetrical triangular wave of amplitude $(R_1/R_2)V_S$ at the output of the integrator.

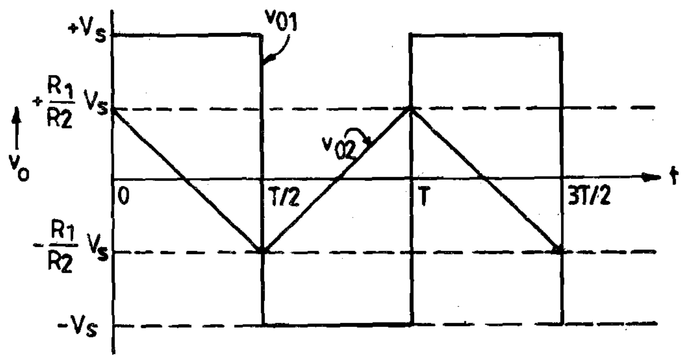

Figure 14.14 (b) : Output Waveforms of the Function Generator Circuit

Example 14.9

A function generator circuit as shown in Figure 14.14(a) uses $R_1 = R_2 = R = 1$ kΩ and $C = 0.1$ μF. Determine the frequency of oscillation of the triangular and square waveforms.

$$f = \frac{R_2}{4RCR_1} = \frac{1}{4 \times 10^3 \times 10^{-7}} \text{ Hz}.$$

$$= 2.5 \text{ kHz}.$$

SAQ 9

Design a function generator circuit for a frequency of oscillation of 1 kHz.

14.4 SUMMARY

This Unit started with the harmonic oscillator equation and its solutions. *LC*-Oscillator as a simple network simulating a differential equation was analysed in the time domain. The frequency domain equivalent of the time domain equation for the oscillator was highlighted. Examples of a variety of *RC*-oscillators were then discussed.

The second part of the Unit started with the use of a high gain amplifier as a comparator. Positive feedback and the advantage of positive feedback for regenerative action was explained. Regenerative comparator as the circuit which has hysteresis behaviour between input and output was illustrated. Its applications in waveshaping, astable multivibrator circuit, monostable action (as Timer) and function generator circuits were discussed.

14.5 ANSWERS TO SAQs

SAQ 1

In the circuit of Figure 14.1

$$2\pi \times 100 \times 10^3 = \frac{1}{\sqrt{10^{-9} \times L}}$$

$$L = \frac{1}{10^{-9} \times 4\pi^2 \times 10^{10}} = 2.533 \text{ mH}$$

$$R_p' = 200 \text{ k}\Omega$$

SAQ 2

In the circuit of Figure 14.3,

$L = CR^2$. $L = 20$ mH

Let $R = 1$ kΩ, $C = \dfrac{L}{R^2} = \dfrac{20 \times 10^{-3}}{10^6}$ F

$= 20$ nF.

SAQ 3

In the circuit of Figure 14.1,

$$\frac{1}{\sqrt{LC}} = 2\pi \times 50 \times 10^3$$

$$LC = \frac{1}{\pi^2 \times 10^{10}}.$$

For $C = 0.01$ μF,

$$L = \frac{1}{10^{-8} \times 10^{10} \times \pi^2} \text{ H} = 1.01 \text{ mH}$$

The circuit of Figure 14.3 may be used to simulate L choosing suitable values for resistors and capacitor.

SAQ 4

In the circuit of Figure 14.5,

$$w = \frac{1}{RC} = 2\pi \times 10^3$$

Taking $R = 10^3$ Ω,

$$C = \frac{1}{2\pi \times 10^3 \times 10^3} \text{ F} = 0.1591 \text{ μF}.$$

SAQ 5

In the circuit of Figure 14.6,

$$w = \frac{1}{RC} = 2\pi \times 10^5.$$

For $R = 1$ kΩ ; $C = \dfrac{1}{2\pi \times 10^5 \times 10^3}$ F

$= 1.591$ nF

SAQ 6

In the circuit of Figure 14.7,

$$w = \frac{1}{\sqrt{6}RC} = 2\pi \times 12 \times 10^3$$

Choose $R = 1$ kΩ ; $C = \dfrac{1}{\sqrt{6} \times 10^3 \times 2\pi \times 12 \times 10^3}$ F

$= 5.415$ nF.

SAQ 7

$$\beta = \frac{1}{2}$$

$$f_0 = \frac{1}{2 \times 10^3 \times 10^{-7} \ln 3}$$

$= 0.4551 \times 10^4$ Hz $= 4.551$ kHz

SAQ 8

$$T = RC \ln 2$$

$$= 10^4 \times 10^{-8} \ln 2 \text{ sec}$$

$$= 69.31 \ \mu \text{ sec.}$$

SAQ 9

The circuit is as shown in Figure 14.14(a).

Let $R = R_2 = R_1 = 10 \text{ k}\Omega$, $10^3 = \dfrac{1}{4RC}$: $C = \dfrac{1}{4 \times 10^4 \times 10^3}$ F.

$\therefore \ C = 25$ nF