## Block Diagram of IC 555

The Fig. 4.9 (a) and (b) show the pin diagram and the block diagram of the IC NE 555 timer. This is 8 pin IC timer.

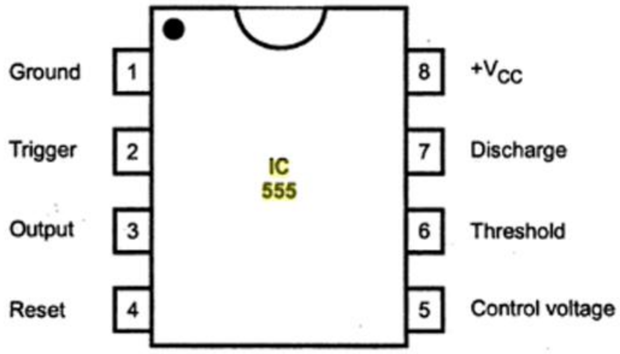


**Fig. 4.9 (a) Pin diagram**

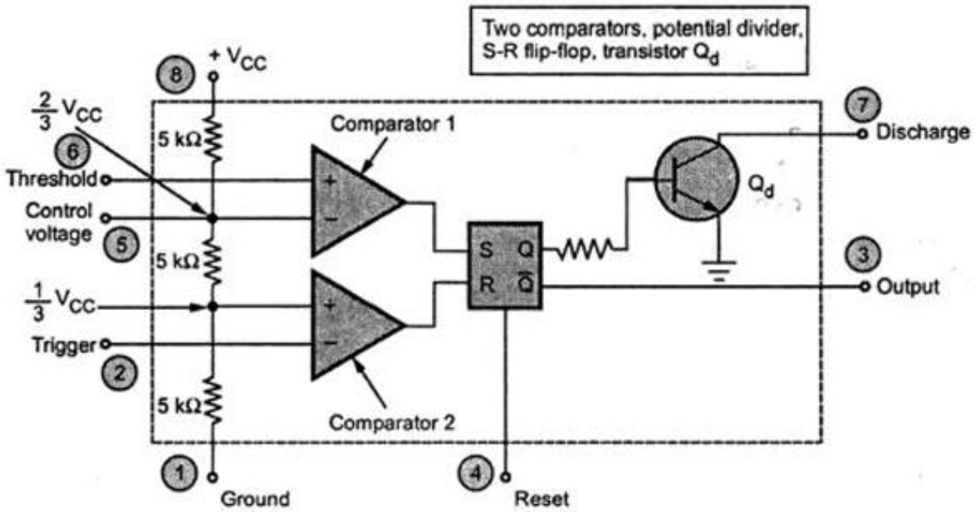


**Fig. 4.9 (b) Block diagram of IC 555 timer**

### 4.5.1 Functions of Pins

The pin numbers of IC 555 and their functions are discussed below :

**Pin 1 : Ground**

All the voltages are measured with respect to this terminal.

**Pin 2 : Trigger**

The IC 555 uses two comparators. The voltage divider consists of three equal resistances. Due to voltage divider, the voltage of noninverting terminal of comparator 2 is fixed at $V_{CC}$ / 3. The inverting input of comparator 2 which is compared with $V_{CC}/3$, is nothing but trigger input brought out as pin number 2. When the trigger input is slightly less than $V_{CC}$ /3 the comparator 2 output goes high. This output is given to reset input of R-S flip-flop. So high output of comparator 2 resets the flip-flop.

**Pin 3 : Output**

The complementary signal output ($\bar{Q}$ ) of the flip-flop goes to pin 3 which is the output. The load can be connected in two ways. One between pin 3 and ground while other between pin 3 and pin 8.

### Pin 4 : Reset

This is an interrupt to the timing device. When pin 4 is grounded, it stops the working of device and makes it off. Thus, pin 4 provides on/off feature to the IC 555. This reset input overrides all other functions within the timer when it is momentarily grounded.

### Pin 5 : Control Voltage Input

In most of the applications, external control voltage input is not used. This pin is nothing but the inverting input terminal of comparator 1. The voltage divider holds the voltage of this input at $2/3\, V_{CC}$. This is reference level for comparator 1 with which threshold is compared. If reference level required is other than $2/3\ V_{CC}$ for comparator 1 then external input is to be given to pin 5.

If external input applied to pin 5 is alternating then the reference level for comparator 1 keeps on changing above and below $2/3\ V_{CC}$. Due to this, the variable pulse width output is possible. This is called **pulse width modulation,** which is possible due to pin 5.

### Pin 6 : Threshold

This is the noninverting input terminal of comparator 1. The external voltage is applied to this pin 6. When this voltage is more than $2/3\ V_{CC}$, the comparator 1 output goes high. This is given to the set input of R-S flip-flop. Thus high output of comparator 1 sets the flip-flop. This makes Q of flip-flop high and $\overline{Q}$ low. Thus the output of IC 555 at pin 3 goes low.

Remember that output at pin 3 is $\overline{Q}$ which is complementary output of flip-flop. In short,

| |
|---|
| For threshold $> \frac{2}{3} V_{CC}$, flip-flop → set, Q → high, output at pin 3 → low |
| For trigger $< \frac{1}{3} V_{CC}$, flip-flop → reset, Q → low, output at pin 3 → high |

### Pin 7 : Discharge

This pin is connected to the collector of the discharge transistor $Q_d$. When the output is high then Q is low and transistor $Q_d$ is off. It acts as an open circuit to the external capacitor C to be connected across it, so capacitor C can charge as described earlier. When output is low, Q is high which drives the base of $Q_d$ high, driving transistor $Q_d$ in saturation. It acts as short circuit, shorting the external capacitor C to be connected across it.

### Pin 8 : Supply $+V_{CC}$

The IC 555 timer can work with any supply voltage between 4.5 V and 16 V.

## 4.6 Monostable Multivibrator using IC 555

The IC 555 timer can be operated as a monostable multivibrator by connecting an external resistor and a capacitor as shown in the Fig. 4.10.

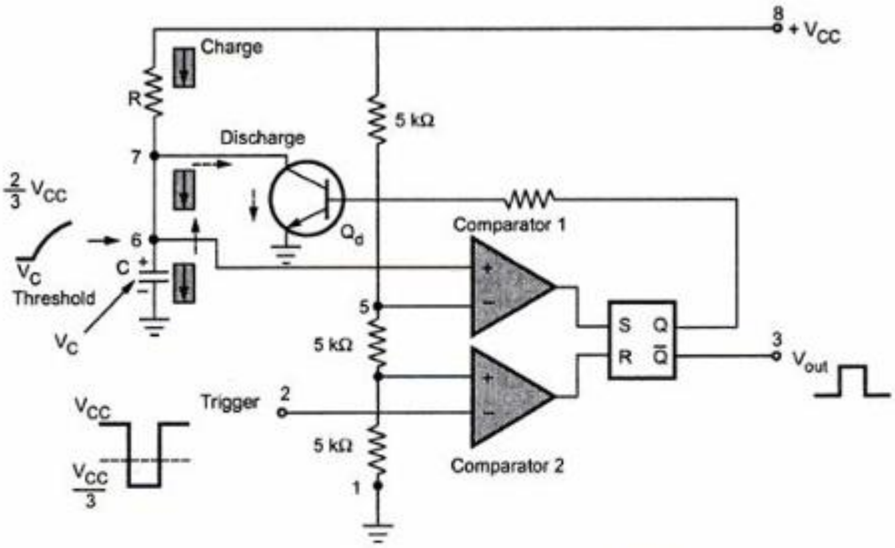


**Fig. 4.10 Monostable operation of 555**

The circuit has **only one stable state**. When trigger is applied, it produces a pulse at the output and returns back to its stable state. The duration of the pulse depends on the values of R and C. As it has only one stable state, it is called one shot multivibrator.

### 4.6.1 Operation

The flip-flop is initially set i.e. Q is high. This drives the transistor $Q_d$ in saturation. The capacitor discharges completely and voltage across it is nearly zero. The output at pin 3 is low.

When a trigger input, a low going pulse is applied, then circuit state remains unchanged till trigger voltage is greater than 1/3 $V_{CC}$. When it becomes less than 1/3 $V_{CC}$, then comparator 2 output goes high. This resets the flip-flop so Q goes low and $\overline{Q}$ goes high. Low Q makes the transistor $Q_d$ off. Hence capacitor starts charging through resistance R, as shown by dark arrows in the Fig. 4.10.

The voltage across capacitor increases exponentially. This voltage is nothing but the threshold voltage at pin 6. When this voltage becomes more than 2/3 $V_{CC}$ , then comparator 1 output goes high. This sets the flip-flop i.e. Q becomes high and $\overline{Q}$ low. This high Q drives the transistor $Q_d$ in saturation. Thus capacitor C quickly discharges through $Q_d$ as shown by dotted arrows in the Fig. 4.11.

So it can be noted that $V_{out}$ at pin 3 is low at start, when trigger is less than 1/3 $V_{CC}$ it becomes high and when threshold is greater than 2/3 $V_{CC}$ again becomes low, till next trigger pulse occurs. So a rectangular wave is produced at the output. The pulse width of this rectangular pulse is controlled by the charging time of capacitor. This depends on the time constant RC. **Thus RC controls the pulse width.** The waveforms are shown in the Fig. 4.11.

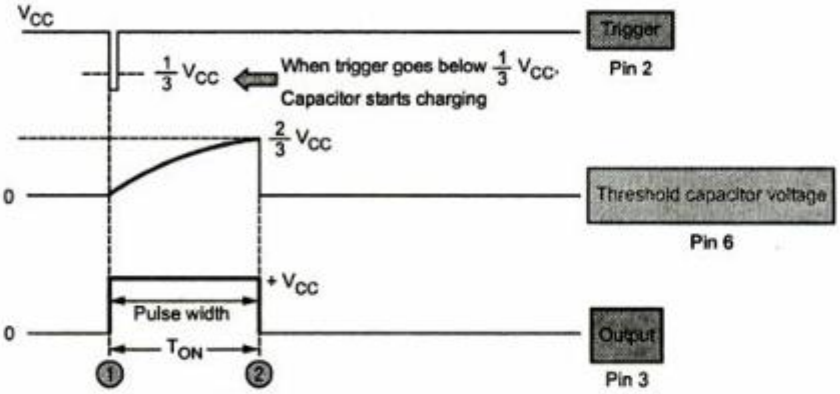


**Fig. 4.11 Waveforms of monostable operation**

### 4.6.2 Derivation of Pulse Width

The voltage across capacitor increases exponentially and is given by

$$V_C = V\left(1 - e^{-t/CR}\right)$$

If $$V_C = 2/3\ V_{CC}$$

then $$\frac{2}{3}V_{CC} = V_{CC}\left(1 - e^{-t/CR}\right)$$

$$\frac{2}{3} - 1 = -e^{-t/CR}$$

$$\frac{1}{3} = e^{-t/CR}$$

$\therefore$ $$-\frac{t}{CR} = -1.0986$$

$\therefore$ $$t = +1.0986\ CR$$

$\therefore$ $$t \approx 1.1\ CR$$

where C in farads, R in ohms, t in seconds.

Thus, we can say that voltage across capacitor will reach 2/3 $V_{CC}$ in approximately 1.1 times, time constant i.e. 1.1 RC

Thus the pulse width denoted as W is given by,

$$\boxed{W = 1.1\ RC}$$

**Example 4.2 :** *Draw the circuit diagram of Timer using IC 555. Calculate the component values if the controlled door should remain open for 15 secs after a trigger signal is received. The dc voltage available is either 10 or 15 volts.*

**Solution :** The requirement is that the door must be open for 15 sec after receiving a trigger signal and then gets shut down automatically. This requires IC 555 in a monostable mode with a pulse width of 15 sec.

$\therefore$ $W = 15$ sec

Now $W = 1.1\ RC$

$\therefore$ $15 = 1.1\ RC$

Choose $C = 100\ \mu F$

$\therefore$ $R = 136.363\ k\Omega$

The designed circuit is shown in the Fig. 4.22.

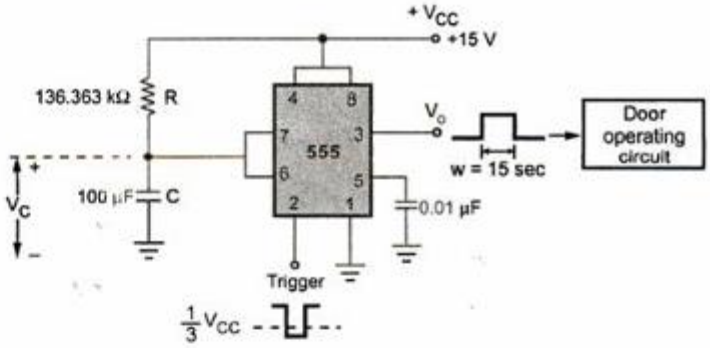


Fig. 4.22

The supply voltage 10 or 15 V has no effect on the operation of the circuit or the values of R and C selected.

## 4.7 Astable Multivibrator using IC 555

The Fig. 4.23 shows the IC 555 connected as an astable multivibrator. The threshold input is connected to the trigger input. Two external resistances $R_A$, $R_B$ and a capacitor C is used in the circuit.

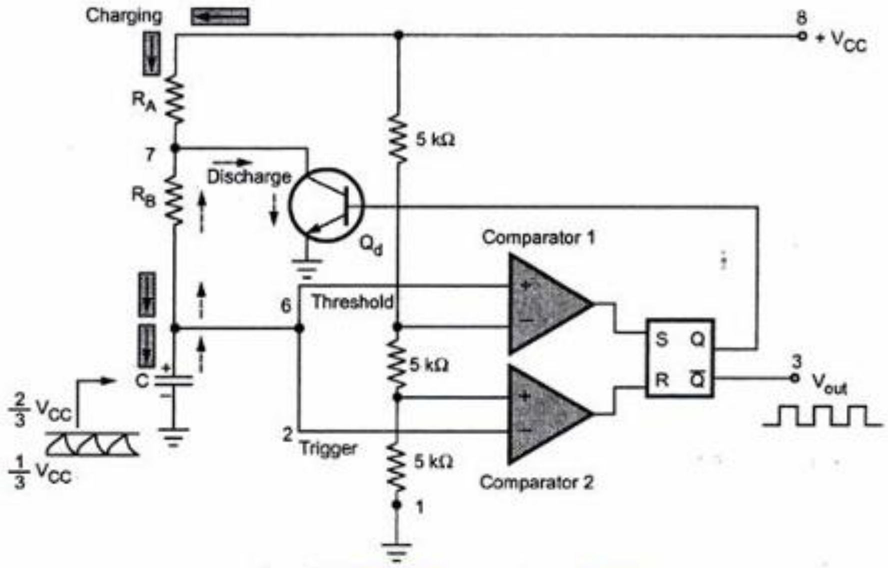


**Fig. 4.23 Astable operation of 555**

**This circuit has no stable state.** The circuits changes its state alternately. Hence the operation is also called free running nonsinusoidal oscillator.

### 4.7.1 Operation

When the flip-flop is set, Q is high which drives the transistor $Q_d$ in saturation and the capacitor gets discharged. Now the capacitor voltage is nothing but the trigger voltage. So while discharging, when it becomes less than 1/3 $V_{CC}$, comparator 2 output goes high. This resets the flip-flop hence Q goes low and $\bar{Q}$ goes high.

The low Q makes the transistor off. Thus capacitor starts charging through the resistances $R_A$, $R_B$ and $V_{CC}$. The charging path is shown by thick arrows in the Fig. 4.23. As total resistance in the charging path is $(R_A + R_B)$, the charging time constant is $(R_A + R_B)$ C.

Now the capacitor voltage is also a threshold voltage. While charging, capacitor voltage increases i.e. the threshold voltage increases. When it exceeds 2/3 $V_{CC}$, then the comparator 1 output goes high which sets the flip-flop. The flip-flop output Q becomes high and output at pin 3 i.e. $\bar{Q}$ becomes low. High Q drives transistor $Q_d$ in saturation and capacitor starts discharging through resistance $R_B$ and transistor $Q_d$. This path is shown by dotted arrows in the Fig. 4.23. Thus the discharging time constant is $R_B$ C. When capacitor voltage becomes less than 1/3 $V_{CC}$, comparator 2 output goes high, resetting the flip-flop. This cycle repeats.

Thus when capacitor is charging, output is high while when it is discharging the output is low. The output is a rectangular wave. The capacitor voltage is exponentially rising and falling. The waveforms are shown in the Fig. 4.24.

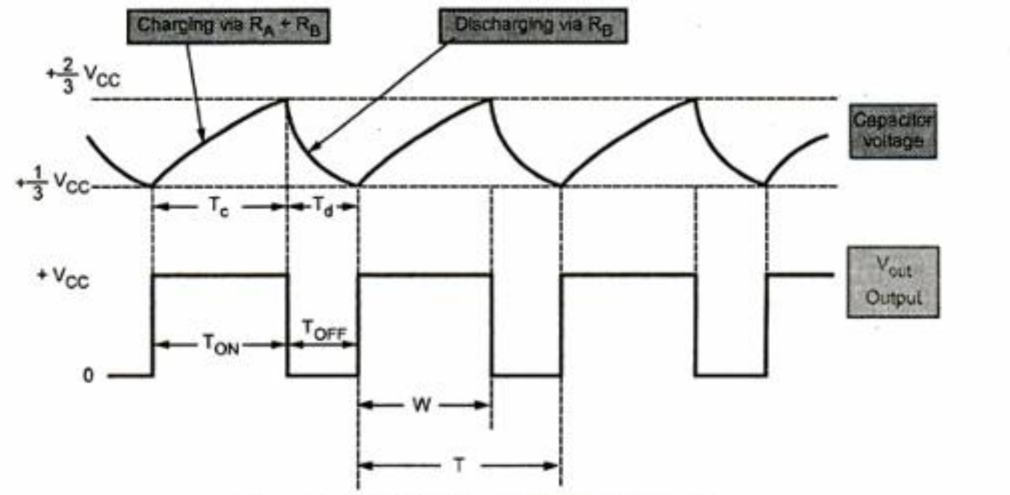


**Fig. 4.24 Waveforms of astable operation**

### 4.7.2 Duty Cycle

Generally the charging time constant is greater than the discharging time constant. Hence at the output, the waveform is not symmetric. The high output remains for longer period than low output. The ratio of high output period and low output period is given by a mathematical parameter called duty cycle. It is defined as the ratio of ON time i.e. high output to the total time of one cycle. As shown in the Fig. 4.24.

$$W = \text{Time for output is high} = T_{ON}$$

$$T = \text{Time of one cycle}$$

$$\therefore \quad D = \text{Duty cycle} = \frac{W}{T}$$

$$\therefore \quad \boxed{\% D = \frac{W}{T} \times 100 \%}$$

The charging time for the capacitor is given by,

$$T_c = \text{Charging time} = 0.693 (R_A + R_B) C$$

While the discharge time is given by,

$$T_d = \text{Discharging time} = 0.693 R_B C$$

Hence the time for one cycle is,

$$T = T_c + T_d = 0.693 (R_A + R_B) C + 0.693 R_B C$$

$$\therefore \quad \boxed{T = 0.693 (R_A + 2 R_B) C}$$

while $\quad W = T_c = 0.693 (R_A + R_B) C$

$\therefore$ $$\% D = \frac{W}{T} \times 100 = \frac{0.693\,(R_A + R_B)\,C}{0.693\,(R_A + 2\,R_B)\,C} \times 100$$

$\therefore$ $$\boxed{\% D = \frac{(R_A + R_B)}{(R_A + 2\,R_B)} \times 100}$$

While the frequency of oscillations is given by,

$$f = \frac{1}{T} = \frac{1}{0.693(R_A + 2\,R_B)C}$$

$\therefore$ $$\boxed{f = \frac{1.44}{(R_A + 2\,R_B)C}\ \text{Hz}}$$

If $R_A$ is much smaller than $R_B$, duty cycle approaches to 50 % and output waveform approaches to square wave.

**Example 4.3 :** *A 555 timer is configured to run in astable mode with $R_A = 4\ k\Omega$, $R_B = 4\ k\Omega$ and $C = 0.01\ \mu F$. Determine the frequency of the output and duty cycle.*

**Solution :** The frequency of output is given by,

$$f = \frac{1.44}{(R_A + 2\,R_B)C} = \frac{1.44}{(4 + 2\times 4)\times 10^3 \times 0.01\times 10^{-6}}$$

$$= \mathbf{12\ kHz}$$

The duty cycle is given by,

$$D = \frac{R_A + R_B}{R_A + 2\,R_B}$$

$$= \frac{4+4}{4+(2\times 4)} = 0.6667$$

Thus the duty cycle is **66.67 %**.

➠ **Example 4.4 :** *Design an astable multivibrator which will flash the electric bulb such that its ON time will be 3 seconds and off time will be 1 seconds.*

**Solution :** Fig. 4.30 shows astable circuit used to drive relay.

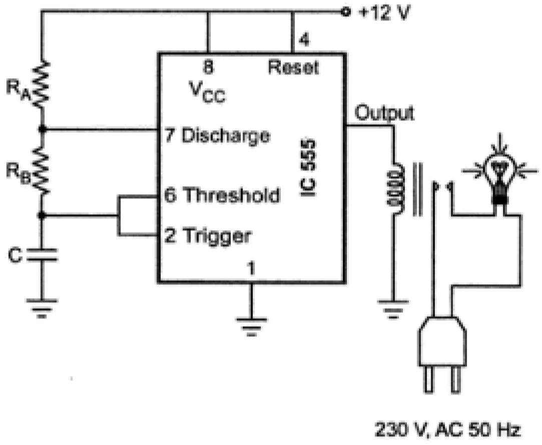


**Fig. 4.30 Astable multivibrator used to flash electric bulb with specific frequency**

This relay should be energized for 3 seconds and then de-energize by 1 seconds.

Hence charging time of capacitor is 3 seconds which is a pulse width W.

$$\therefore \quad W = 3 \text{ seconds}$$

While total time of one cycle is,

$$\therefore \quad T = 3 + 1 = 4 \text{ seconds}$$

$$\therefore \quad D = \frac{W}{T} = \frac{3}{4} = \text{duty cycle}$$

$$= 0.75$$

But
$$D = \frac{R_A + R_B}{R_A + 2R_B}$$

$$\therefore \quad 0.75 = \frac{R_A + R_B}{R_A + 2R_B}$$

$$\therefore \quad R_A + 2R_B = 1.33 R_A + 1.33 R_B$$

$$\therefore \quad 0.667 R_B = 0.333 R_A$$

$$\therefore \quad R_A = 2 R_B \quad \dots (1)$$

Now the charging time is given by,

$$T_c = 0.693 (R_A + R_B) C$$

$$\therefore \quad 3 = 0.693 (R_A + R_B) C$$

Choose $C = 10\ \mu F$

$\therefore \quad R_A + R_B = \frac{3}{0.693 \times 10 \times 10^{-6}}$

$\therefore \quad R_A + R_B = 4.329 \times 10^5$ ... (2)

Solving equations (1) and (2) we get,

$R_A = \mathbf{288.6\ k\Omega}$

$R_B = \mathbf{144.3\ k\Omega}$

The values are not standard but can be adjusted using the potentiometers.

**Example 4.7 :** *Draw the circuit diagram of an astable multivibrator to generate the output signal with frequency of 1 kHz and the duty cycle of 75 %.*

**Solution :** $f = 1$ kHz

$D = 75\ \% = 0.75$

Now $f = \frac{1.44}{(R_A + 2R_B)C}$ Hz

$\therefore \quad 1 \times 10^3 = \frac{1.44}{(R_A + 2R_B)C}$

$\therefore \quad (R_A + 2R_B)\,C = 1.44 \times 10^{-3}$ ...(1)

$\therefore$ while $\%D = \frac{(R_A + R_B)}{(R_A + 2R_B)} \times 100$

$\therefore \quad 0.75 = \frac{R_A + R_B}{R_A + 2R_B}$

$\therefore \quad R_A + 2R_B = \frac{(R_A + R_B)}{0.75}$

$\therefore \quad R_A + 2R_B = 1.33\,(R_A + R_B)$

$\therefore \quad 0.66\,R_B = 0.33\,R_A$

$\therefore \quad R_B = 0.5\,R_A$ ...(2)

Choose $C = \mathbf{0.1\ \mu F}$

Substituting in equation (1),

$(R_A + 2R_B) \times 0.1 \times 10^{-6} = 1.44 \times 10^{-3}$

$\therefore \quad R_A + 2R_B = 14400$ ...(3)

Substituting equation (2) in equation (3),

$R_A + 2\,(0.5\,R_A) = 14400$

$\therefore \quad R_A = \mathbf{7.2\ k\Omega}$

$\therefore \quad R_B = \mathbf{3.6\ k\Omega}$

and $C = 0.1\ \mu F$

Hence the circuit diagram is as shown in the Fig. 4.35.

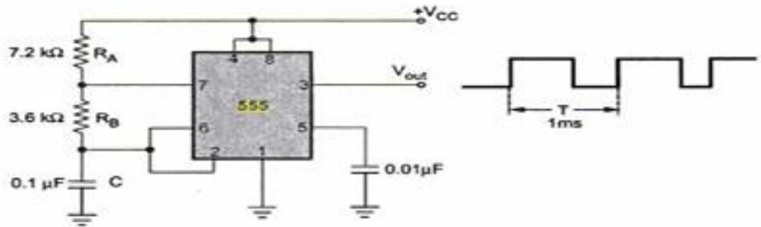


Fig. 4.35

**Example 4.8 :** *An astable multivibrator is to be designed for getting rectangular waveform with $t_{ON} = 0.6$ ms. Draw the circuit diagram with various component values. Also calculate frequency of oscillations and duty cycle. Assume total time period (T) to be 1 ms.*

**Solution :** $T_{ON} = 0.6$ ms, T = 1 ms

$\therefore$ $$D = \frac{t_{ON}}{T} = \frac{0.6}{1} = 60\ \%$$

Now $$D = \frac{R_A + R_B}{R_A + 2R_B} = 0.6$$

$\therefore$ $$R_A + R_B = 0.6\ R_A + 1.2\ R_B$$

$\therefore$ $$0.4\ R_A = 0.2\ R_B$$

$\therefore$ $$R_B = 2\ R_A$$

$$f = \frac{1.44}{(R_A + 2R_B)C} = \frac{1}{T} = 1000$$

Choose C = **0.1 μF**

$\therefore$ $$R_A + 2R_B = 14400$$

Using equation (1), $$5R_A = 14400$$

$\therefore$ $$R_A = \mathbf{2.88\ k\Omega}, \quad R_B = \mathbf{5.77\ k\Omega}$$

The circuit is shown in the Fig. 4.36.

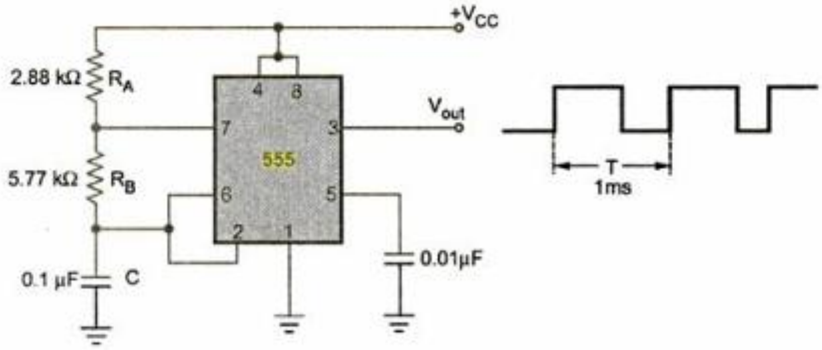


**Fig. 4.36**

## 4.8 Comparison of Multivibrator Circuits

| Sr. No. | Monostable multivibrator | Astable multivibrator |
|---|---|---|
| 1. | It has only one stable state. | There is no stable state. |
| 2. | Trigger is required for the operation, to change the state. | Trigger is not required to change the state, hence called free running. |
| 3. | Two components R and C are necessary with IC 555 to obtain the circuit. | Three components $R_A$, $R_B$ and C are necessary with IC 555 to obtain the circuit. |
| 4. | The pulse width is given by, $W = 1.1\ RC$ seconds | The frequency is given by, $f = \frac{1.44}{(R_A + 2R_B)}$ Hz |
| 5. | The frequency of operation is controlled by frequency of trigger pulses applied. | The frequency of operation is controlled by $R_A$, $R_B$ and C. |
| 6. | The applications are, timer, frequency divider, pulse width modulation etc. | The applications are square wave generator, flasher, voltage controlled oscillator, FSK generator etc. |

## 4.11 555 Timer as a Schmitt Trigger

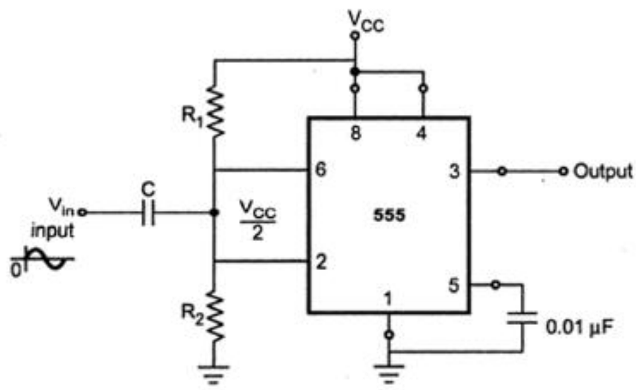


**Fig. 4.38 555 as a schmitt trigger**

The Fig. 4.38 shows the use of 555 timer as a schmitt trigger.

The input is given to the pins 2 and 6 which are tied together. Pins 4 and 8 are connected to supply voltage $+V_{CC}$. The common point of two pins 2 and 6 is externally biased at $V_{CC}/2$ through the resistance network $R_1$ and $R_2$. Generally $R_1 = R_2$ to get the biasing of $V_{CC}/2$. The upper comparator will trip at $2/3\ V_{CC}$ while lower comparator at $1/3\ V_{CC}$. The bias provided by $R_1$ and $R_2$ is centred within these two thresholds.

Thus when sine wave of sufficient amplitude, greater than $V_{CC}/6$ is applied to the ciruit as input, it causes the internal flip-flop to alternately set and reset. Due to this, the circuit produces the square wave at the output, as shown in the Fig. 4.39.

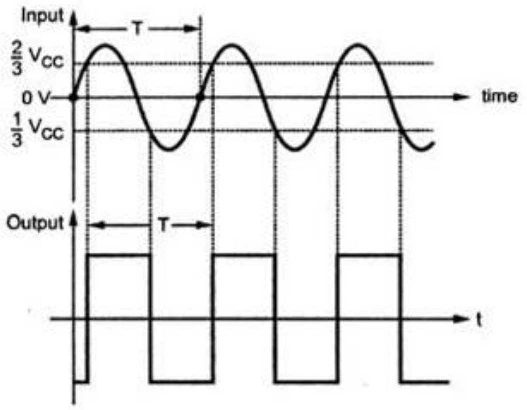


**Fig. 4.39**

The frequency of square wave remains same as that of input. The Schmitt trigger can operate with the input frequencies upto 50 kHz.

**Bistable Multivibrator**

In these circuits, the output is stable in both the states. The states are switched using an external trigger but unlike the monostable multivibrator, it does not return back to its original state. Another trigger is needed for this to happen. This operation is similar to a flip-flop. There are no RC timing network and hence no design parameters. The following circuit can be used to design a bistable multivibrator. The trigger and reset inputs (pins 2 and 4 respectively on a 555) are held high via pull-up resistors while the threshold input (pin 6) is simply grounded. Thus configured, pulling the trigger momentarily to ground acts as a 'set' and transitions the output pin (pin 3) to Vcc (high state). Pulling the threshold input to supply acts as a 'reset' and transitions the output pin to ground (low state). No capacitors are required in a bistable configuration.

**Circuit Diagram:**