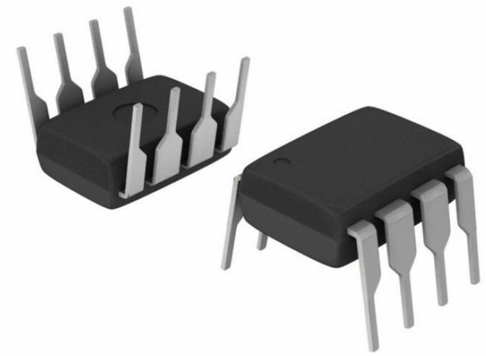
# Digital Electronics

## *555 Timer*

# What is IC 555?

- The IC 555 timer is a one type of chip used in different applications like an oscillator, pulse generation, timer.



- The operating range of this IC ranges from 4.5V -15V DC supply.

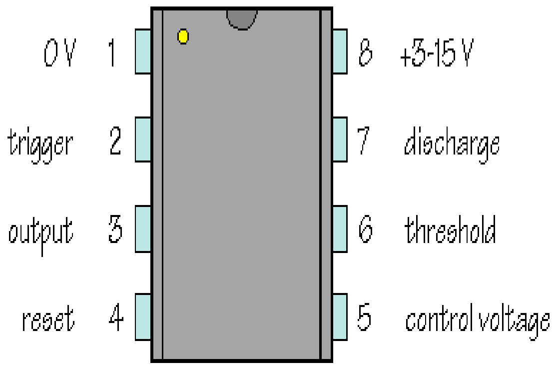
- The functional parts of the 555 timer IC include flip-flop, voltage divider and a comparator.

- The main function of this IC is to generate an accurate timing pulse.

# Pin configuration of IC 555

- **GND Pin:** Pin-1 is a GND pin which is used to supply a zero voltage to the IC.
- **Trigger Pin:** Pin-2 is a trigger pin which is used to convert the FF from set to reset. The output of the timer depends on the amplitude of the external trigger pulse that is applied to the trigger pin.
- **Output Pin:** Pin-3 is an output pin.
- **Reset Pin:** Pin-4 is a Reset pin. When the negative pulse is applied to this pin to disable or reset, a false triggering can be neglected by connecting to VCC.

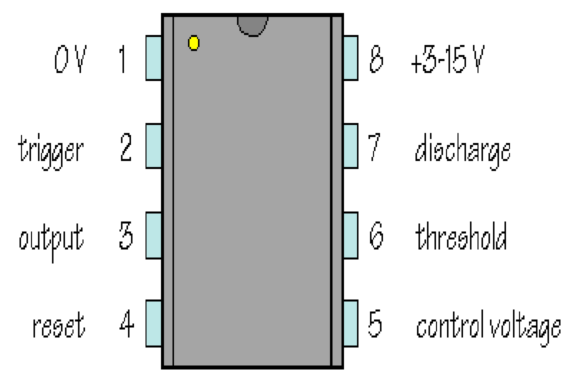
DIP chip (Dual-Inline package)



# Pin configuration of IC 555 (*contd…*)

- **Control Voltage Pin:** Pin-5 is the control voltage pin used to control the pulse width of the output waveform and also the levels of threshold and trigger. When an external voltage is applied to this pin, then the output waveform will be modulated
- **Threshold Pin:** Pin-6 is the threshold pin, when the voltage is applied to threshold pin, then it contrasts with a reference voltage. The set state of the FF can be depends on the amplitude of this pin.
- **Discharge Pin:** Pin-7 is the discharge pin, when the output of the open collector discharges a capacitor between the intervals, then it toggles the output from high to low.
- **Supply Terminal:** Pin-8 is the voltage supply pin which is used to supply the voltage to the IC with respect to the ground terminal.

DIP chip (Dual-Inline package)



# Basic Operation of IC 555

- When the normally HIGH trigger input momentarily goes below 1/3 Vcc, the output of comparator B switches from LOW to HIGH and sets the S-R latch (Q=1). causing the output (pin 3) to go HIGH and turning the discharge transistor Q1 off.

- When the LOW threshold input goes above 2/3 Vcc and causes the output of comparator A to switch from LOW to HIGH. This resets the latch (Q=0), causing the output (pin 3) to go back LOW and turning the discharge transistor on.

- Note: The trigger and threshold inputs are controlled by external components connected to produce either monostable or astable action.

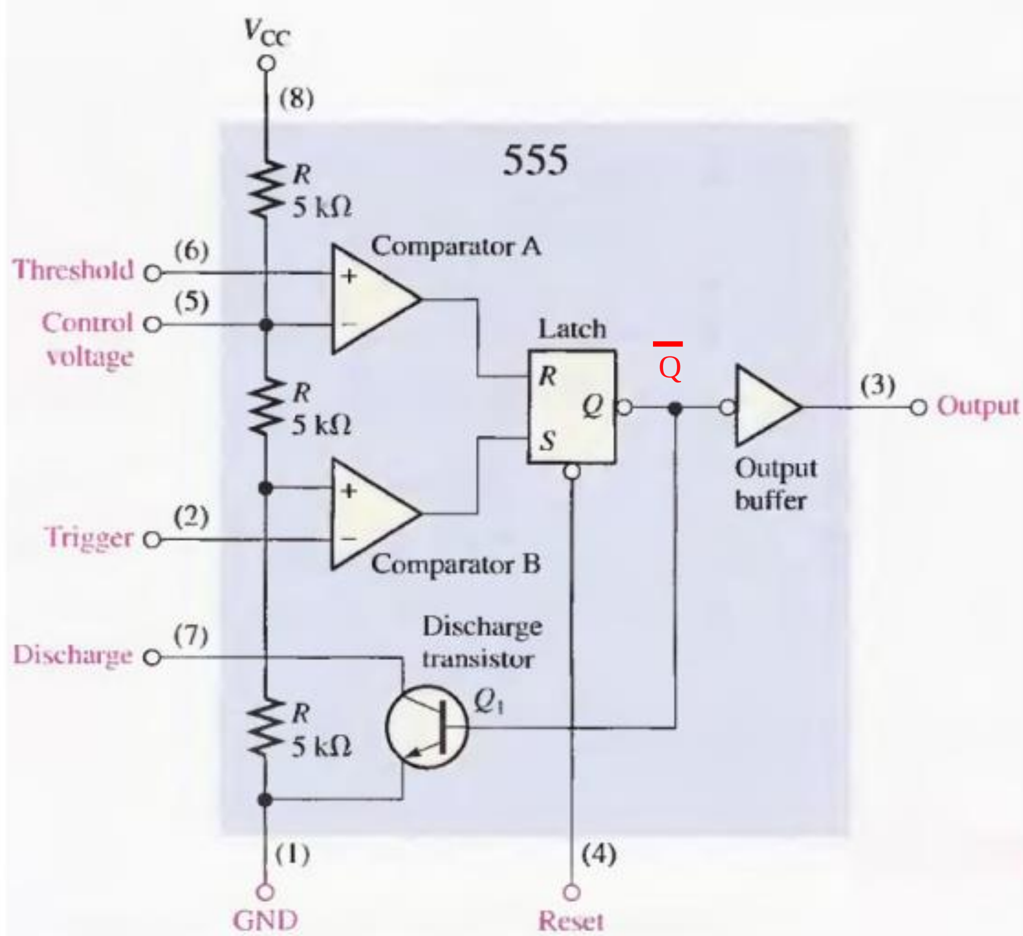



**Fig 1. Internal functional diagram of a 555 timer.**

# Modes of IC 555 timer

- Time Delay Mode

- In the time delay mode, the delay is controlled by one external resistor and capacitor.
- Also Known as **Monostable (One-shot) mode.**

**Example:** Turn a light ON in a delayed amount of time. (Just turn ON or OFF once)

- Oscillator Mode

- In the oscillator mode, the frequency of oscillation are controlled with two external resistors and one capacitor.
- Also known as **Astable mode.**

**Example:** Can make a light flash a specific rate. (Can turn ON and OFF repeatedly)

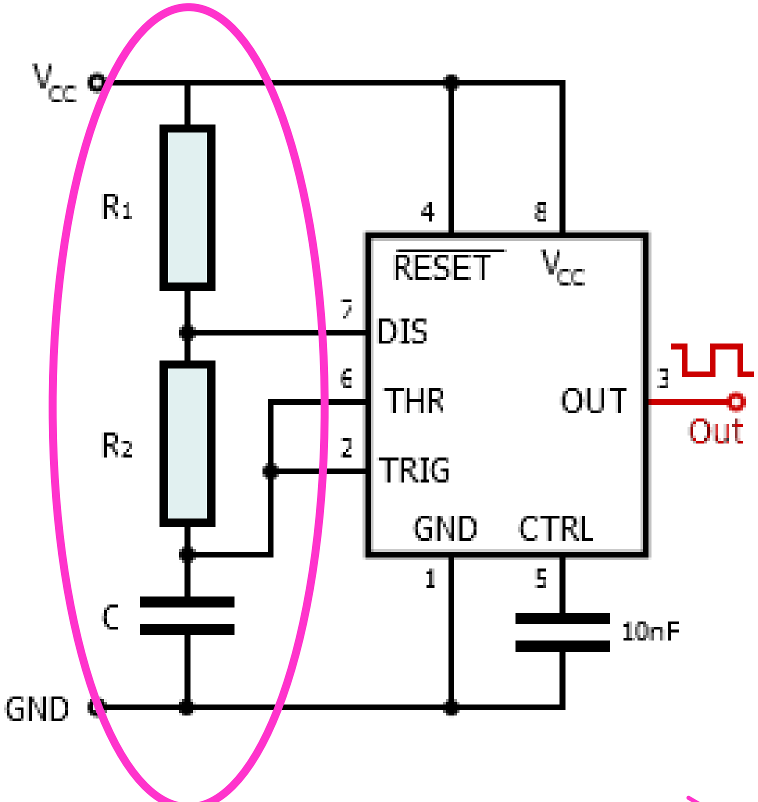
- Another mode is Bistable Mode

# IC 555 timer : *Astable Mode*

Astable multivibrator mode schematic

Notice:

- 2 resistors
- 1 capacitor
- OUTPUT is square wave pulses



# IC 555 timer : *Astable Mode*

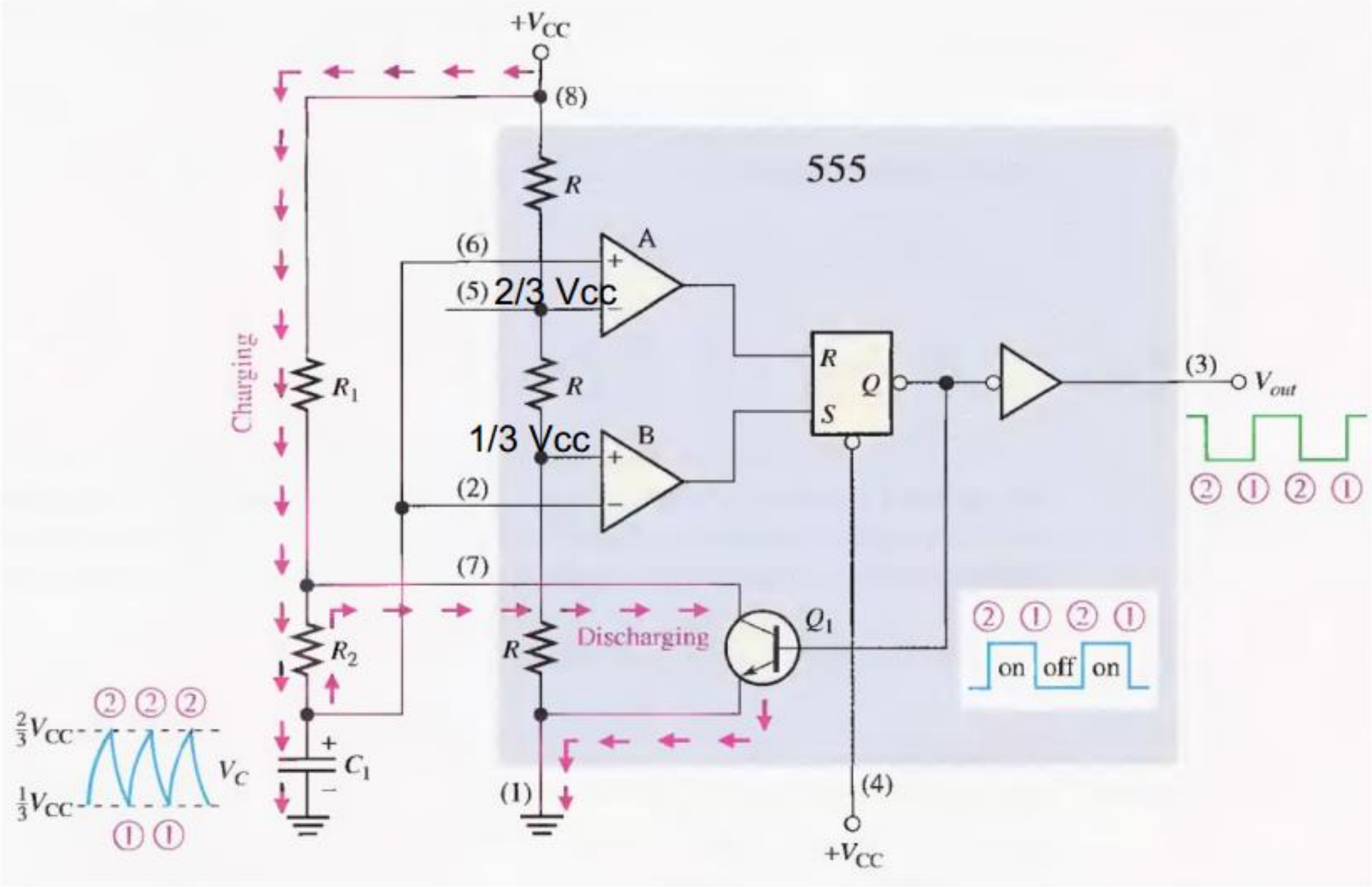



Fig. Operation of the 555 timer in the astable mode.

# IC 555 timer : *Astable Mode*

Operation

- Initially, when the power is just turned on, the capacitor (C1) remain '**Uncharged'** and thus the trigger (pin 2) and threshold (pin 6) is at **0 V**. So, Vout (comp. A) = 0 and Vout (comp. B) = 1. That's why Q1 is **OFF.**

- Now, **C1** begins **charging** through R1 and R2, indicated in Figure. When, C1 is just above 2/3Vcc then Vout= (comp A)=1 and Vout= (comp B)=0 which Resets the latch (Q=0).

- At this state **Q1** turns **ON** and creates a **discharging** path as shown in the figure. When C1 discharge it causes Vout (comp. A)=0 and when C1 discharges down to 1/3Vcc then Vout (comp. B)=1.

- This again Sets latch and turning off Q1 again. Another charging cycle begins and the entire process repeats.

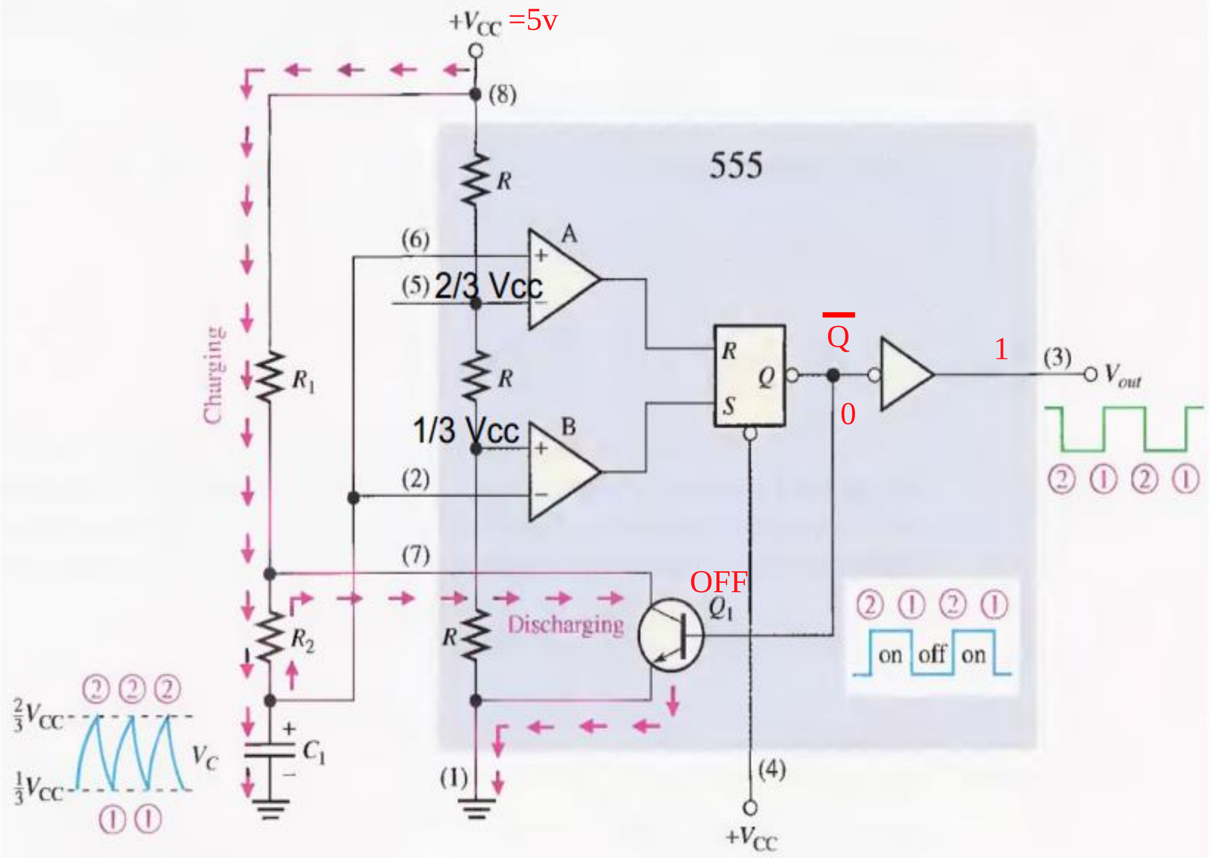
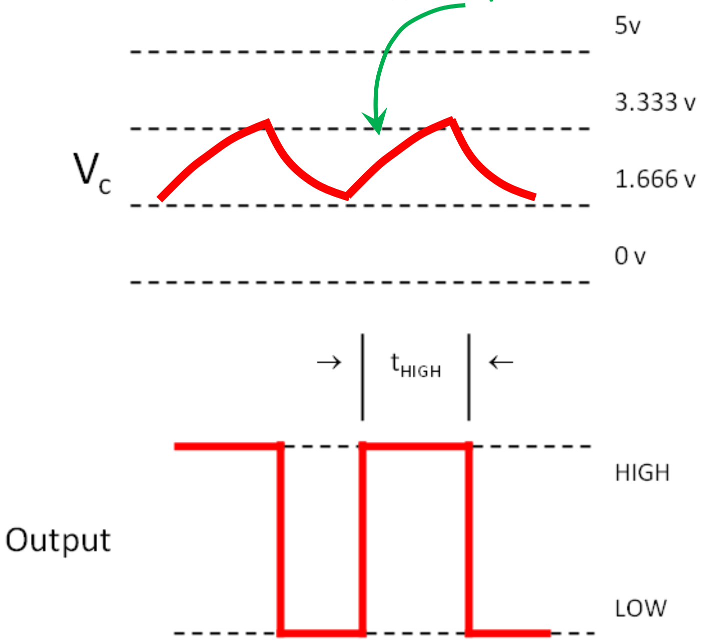


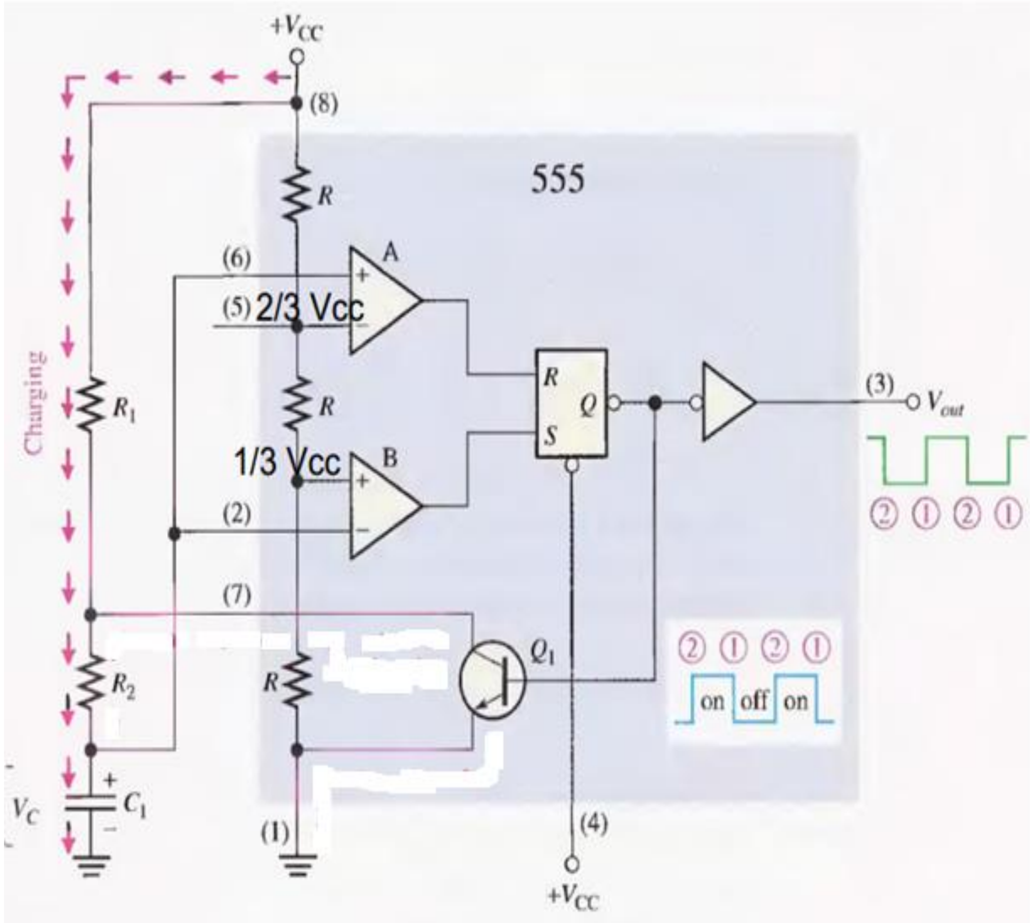

Fig. Operation of the 555 timer in the astable mode.

# IC 555 timer : *Astable Mode*

## $t_{HIGH}$ : Calculations for the Oscillator's HIGH Time

THE OUTPUT IS HIGH WHILE THE CAPACITOR IS CHARGING THROUGH $R_A + R_B$.



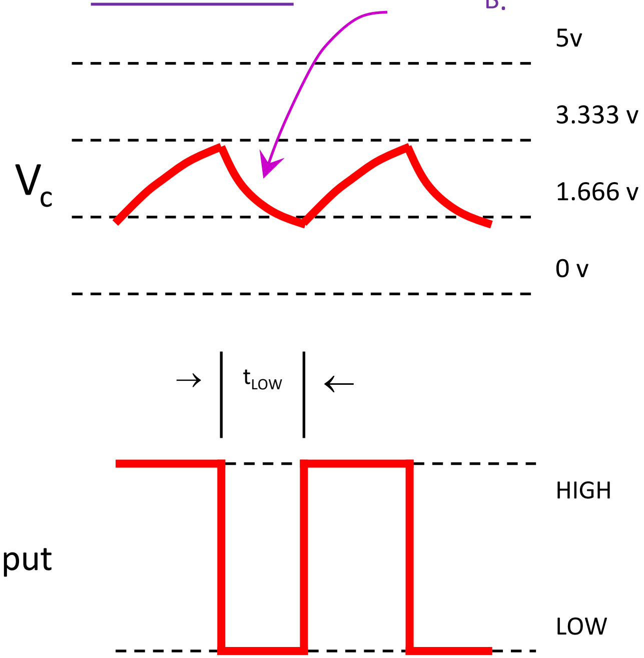



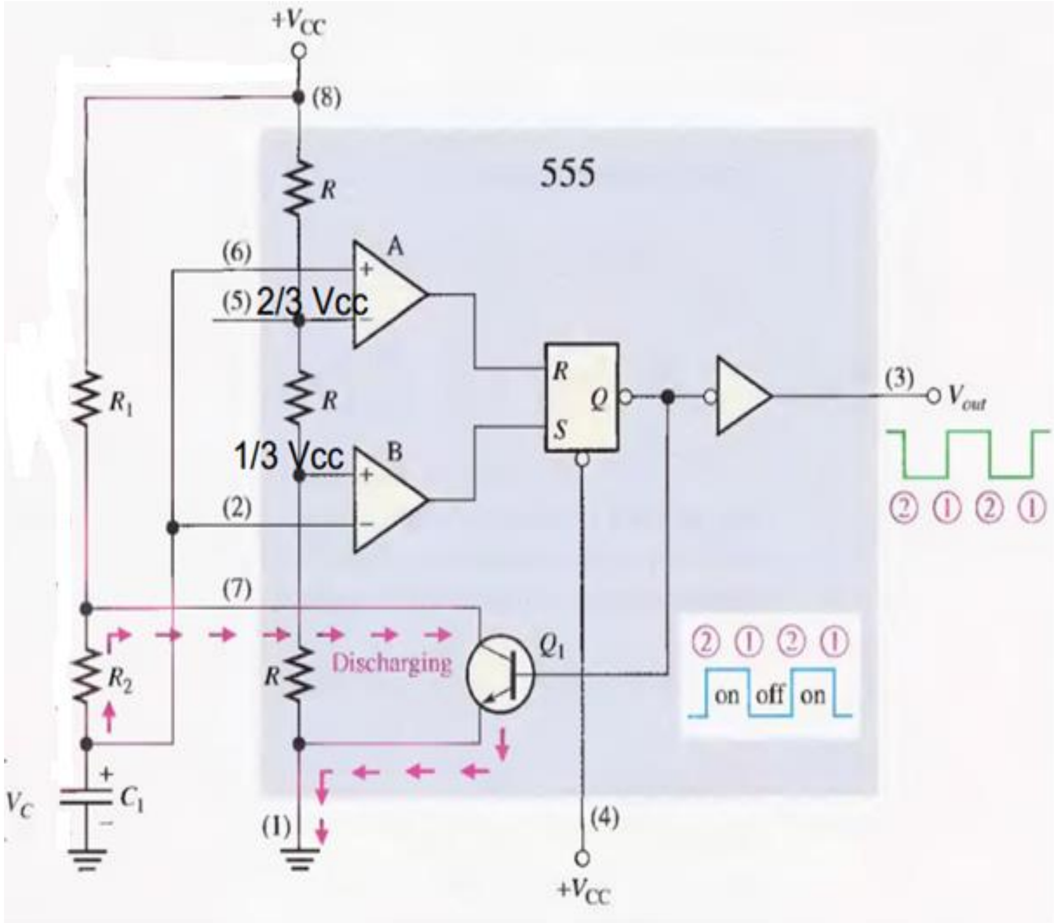

$$t_{HIGH} = 0.693(R_A + R_B)C$$

# IC 555 timer : *Astable Mode*

## $t_{LOW}$ : Calculations for the Oscillator's LOW Time

THE OUTPUT IS LOW WHILE THE CAPACITOR IS DISCHARGING THROUGH $R_B$.



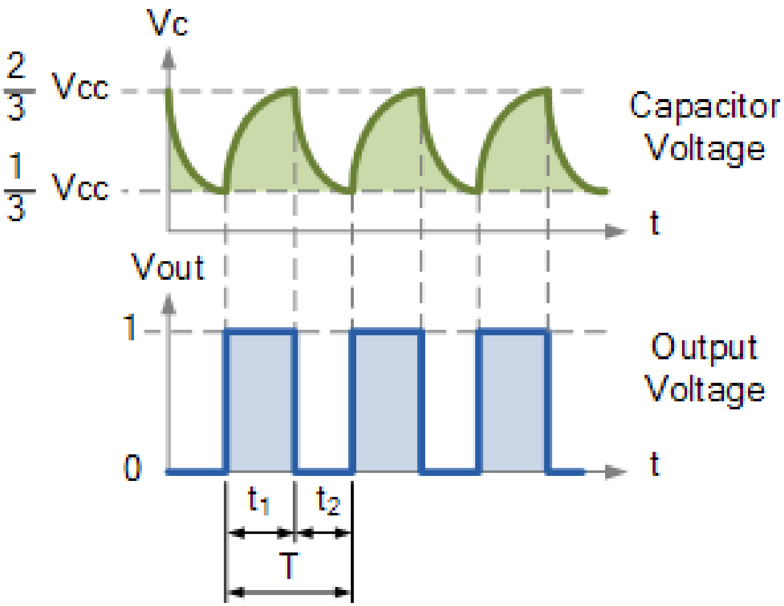




$$t_{LOW} = 0.693 R_B C$$

# IC 555 timer : *Astable Mode*

**Time Period:**

**The Period is the total time of an on/off cycle and depends on the values of $R_A$, $R_B$, and C**




$$t_{HIGH} = 0.693\left(R_A + R_B\right)C$$

$$t_{LOW} = 0.693\, R_B C$$

$$T = t_{HIGH} + t_{LOW}$$

$$T = \left[0.693\left(R_A + R_B\right)C\right] + \left[0.693\, R_B C\right]$$

$$T = 0.693\left(R_A + 2R_B\right)\mathrm{C}$$

Notes:

- The value 0.693 is a factor associated with the charge/discharge cycle of the 555 timer.

# IC 555 timer : *Astable Mode*

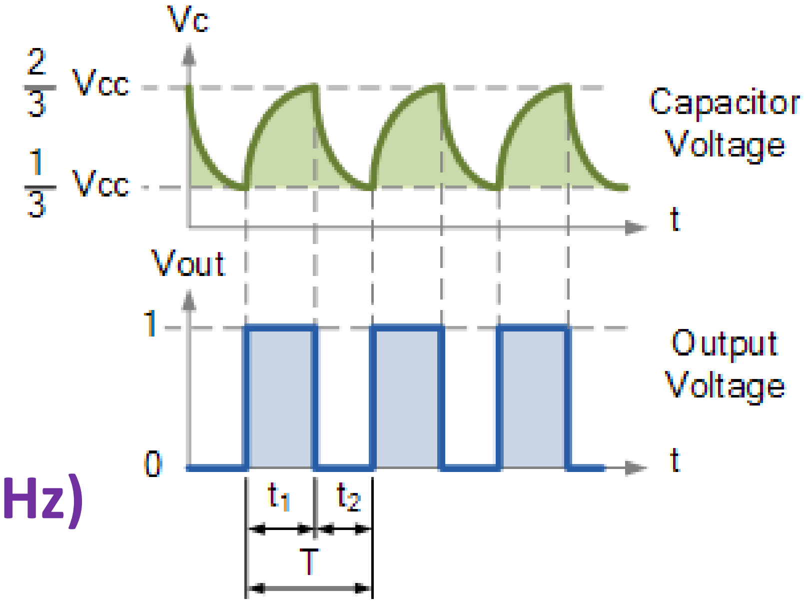
**Frequency :**

**The frequency of an oscillation (or anything that exhibits a repeating pattern) is inversely proportional to the period**

$$F = \frac{1}{T}$$

*Unit of Measure:*

cycles/second = Hertz **(Hz)**




$$F = \frac{1}{0.693\left(R_A + 2R_B\right)C}$$

# Mathematical Problem

- **Design an oscillator for a frequency of 200Hz with a duty cycle of 78%. Determine time period, high & low time, $R_B$ and $R_A$ (assume C=10µF)**

1. Determine Period (T):

$$T = \frac{1}{F} = \frac{1}{200Hz} = 0.005s$$

2. Determine $T_H$ and $T_L$:

$$T_H = 78\% \bullet 0.005s = 0.0039s = 3.9ms$$
$$T_L = 22\% \bullet 0.005s = 0.0011s = 1.1ms$$

# Mathematical Problem (*contd…*)

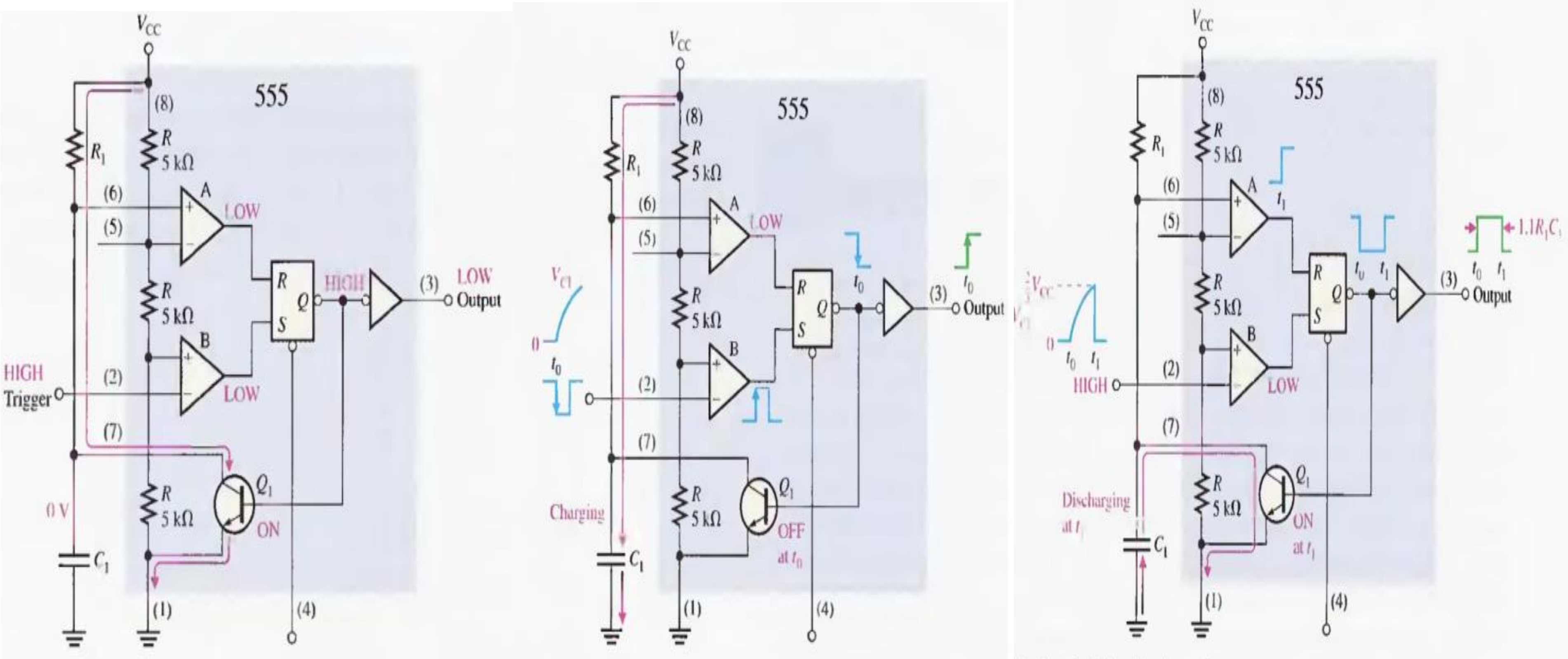
3. Determine $R_B$ by using the $T_L$ equation:

$$T_L = 0.693 R_B C$$
$$1.1\text{ms} = 0.693 \bullet R_B \bullet 10\mu F$$
$$R_B = 158.7\Omega$$

4. Determine the value of $R_A$:

$$T_H = 0.693(R_A + R_B)C$$
$$3.9\text{ms} = 0.693(R_A + 158.7\Omega)10\mu F$$
$$562.8\Omega = R_A + 158.7\Omega$$
$$R_A = 404.1\Omega$$

# IC 555 timer : *Monostable Mode*

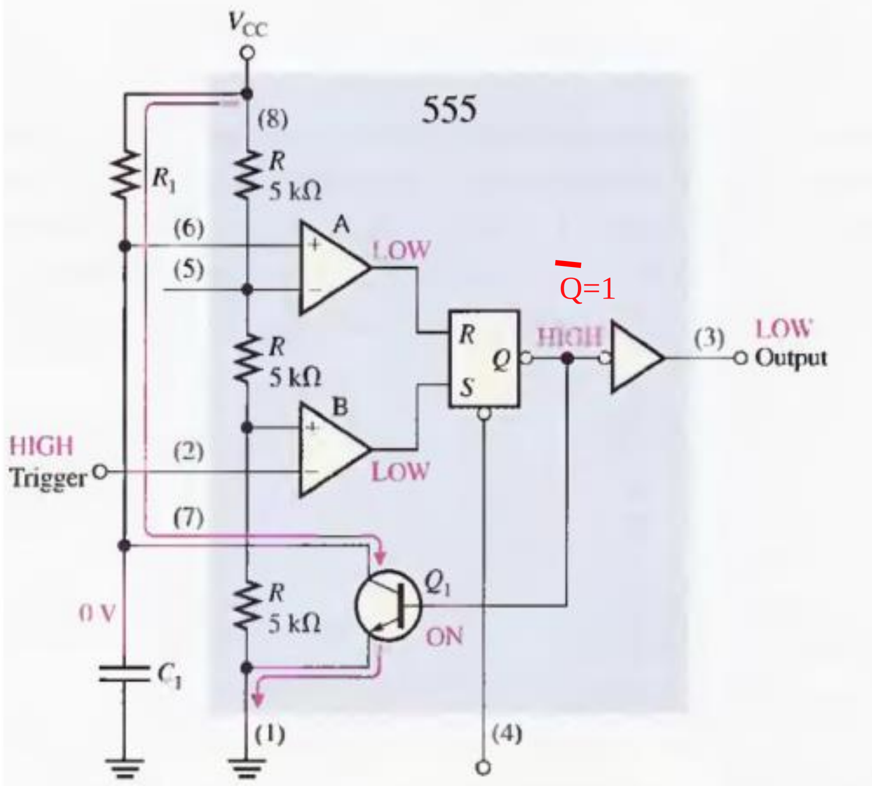



(a) Prior to triggering. (The current path is indicated by the red arrow. (b) When triggered (c) At end of charging interval

# IC 555 timer : *Monostable Mode*

**Before a trigger** pulse is applied, the output is LOW (***Stable off-state***) and the discharge transistor Q1 is ON, keeping C1 discharged as shown in Figure.

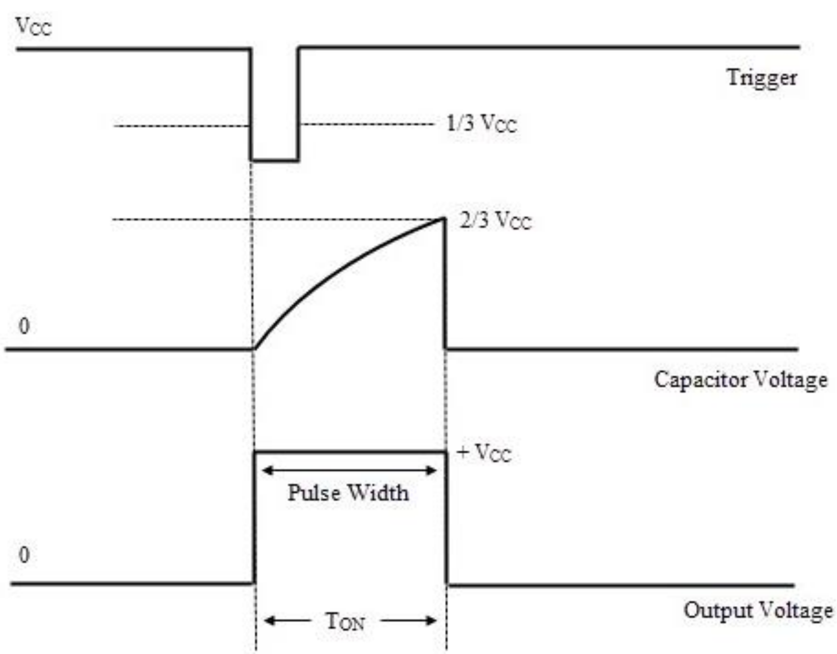
*Note: Before a trigger pulse, it is equal to Vcc .*

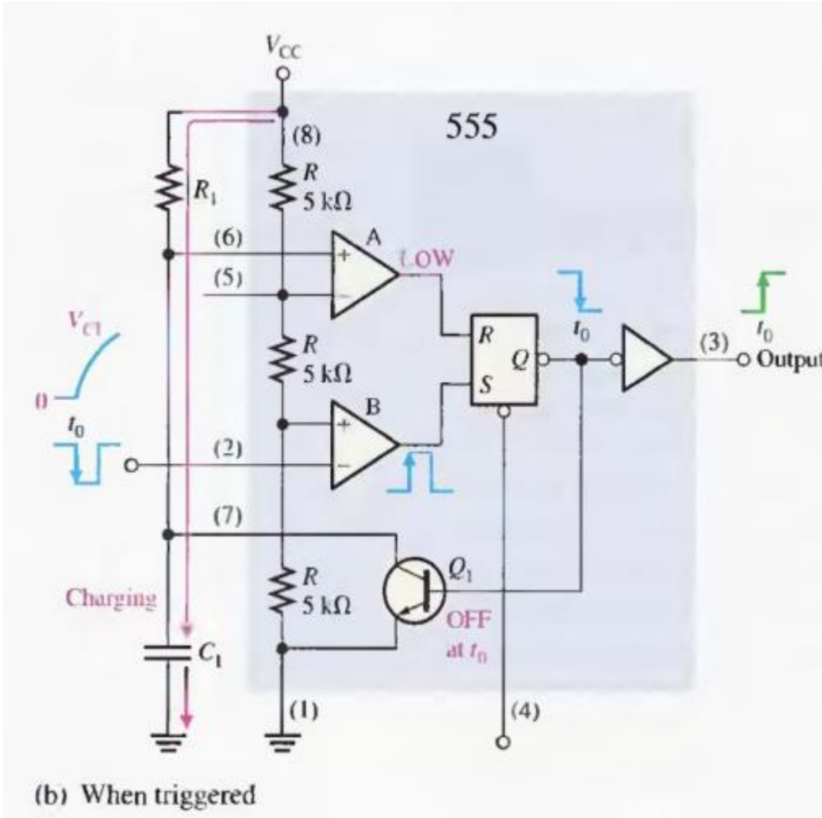



(a) Prior to triggering. (The current path is indicated by the red arrow.)

# IC 555 timer : *Monostable Mode*

**At time, $t_0$** a negative going triggering pulse is applied and it becomes less than 1/3Vcc; then (+ve) i/p > (-ve) i/p for comp. B.



(b) When triggered

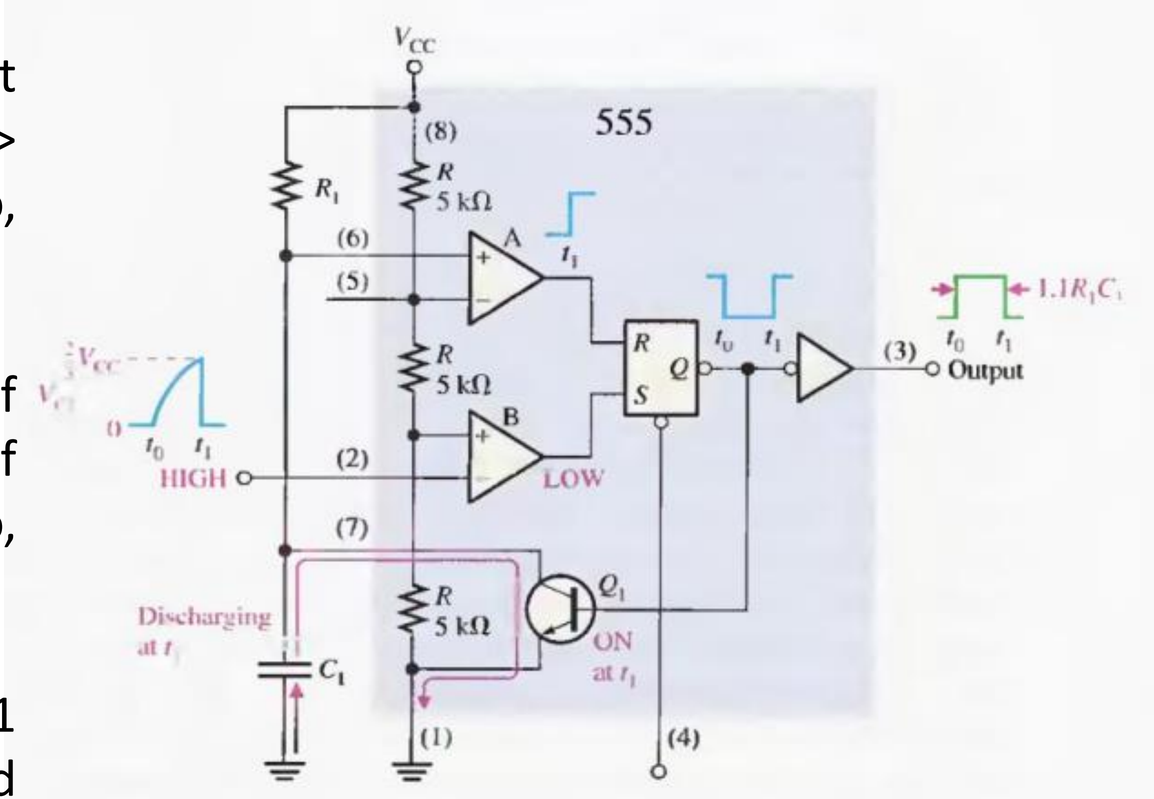
So, **Comp. B = 1** which makes Output = High. Q1 is off and allowing C1 to charge through R1 as shown in Figure.

# IC 555 timer : *Monostable Mode*

**At time, $t_1$** when C1 is just above 2/3 Vcc then (+ve) i/p > (-ve) i/p for comp. A. So, **Comp. A = 1.**

At the same time, (-ve) i/p of comp. B ( **HIGH**) > (+ve) i/p of comp. B (1/3 of Vcc). So, **comp. B = 0.**

Thus **o/p = 0** (LOW) at t1 state. This turns on Q1 and helps C1 to discharge.



(c) At end of charging interval

- The pulse width of the output is determined by the time constant of $R_1$ and $C_1$ :

$$t_w = 1.1\ R_1\ C_1$$

Thank You

Figure 7–51 shows three 74LS122 one-shots connected as a sequential timer. This particular circuit produces a sequence of three 1 s pulses. The first one-shot is triggered by a switch closure or a low-frequency pulse input, producing a 1 s output pulse. When the first one-shot (OS 1) times out and the 1 s pulse goes LOW, the second one-shot (OS 2) is triggered, also producing a 1 s output pulse. When this second pulse goes LOW, the third one-shot (OS 3) is triggered and the third 1 s pulse is produced. The output timing is illustrated in the figure. Variations of this basic arrangement can be used to produce a variety of timed outputs.

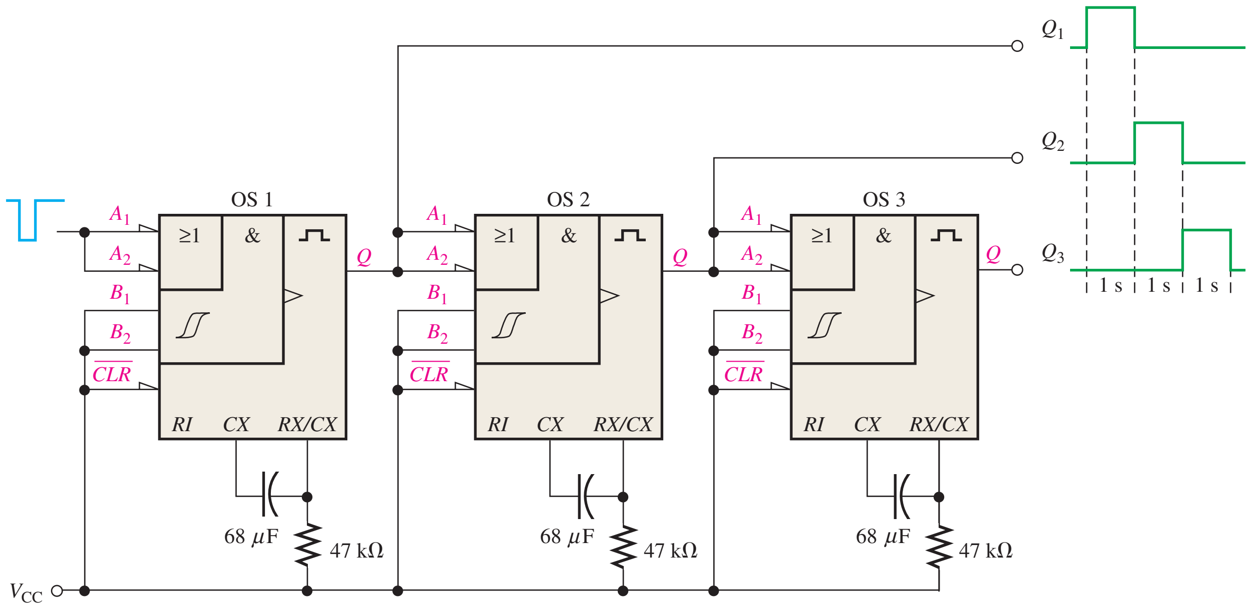



**FIGURE 7–51** A sequential timing circuit using three 74LS122 one-shots.

## The 555 Timer as a One-Shot

The 555 **timer** is a versatile and widely used IC device because it can be configured in two different modes as either a monostable multivibrator (one-shot) or as an astable multivibrator (pulse oscillator). The astable multivibrator is discussed in Section 7–6.

### The 555 Timer Operation

A functional diagram showing the internal components of a 555 timer is shown in Figure 7–52. The comparators are devices whose outputs are HIGH when the voltage on the positive (+) input is greater than the voltage on the negative (−) input and LOW when the − input voltage is greater than the + input voltage. The voltage divider consisting of three 5 kΩ resistors provides a trigger level of $^{1}/_{3}\,V_{CC}$ and a threshold level of $^{2}/_{3}\,V_{CC}$. The control voltage input (pin 5) can be used to externally adjust the trigger and threshold levels to other values if necessary. When the normally HIGH trigger input momentarily goes below $^{1}/_{3}\,V_{CC}$, the output of comparator B switches from LOW to HIGH and sets the S-R latch, causing the output (pin 3) to go HIGH and turning the discharge transistor $Q_1$ off. The output will stay HIGH until the normally LOW threshold input goes above $^{2}/_{3}\,V_{CC}$ and causes the output of comparator A to switch from LOW to HIGH. This resets the latch, causing the output to go back LOW and turning the discharge transistor on. The external reset input can be used to reset the latch independent of the threshold circuit. The trigger and threshold inputs (pins 2 and 6) are controlled by external components connected to produce either monostable or astable action.

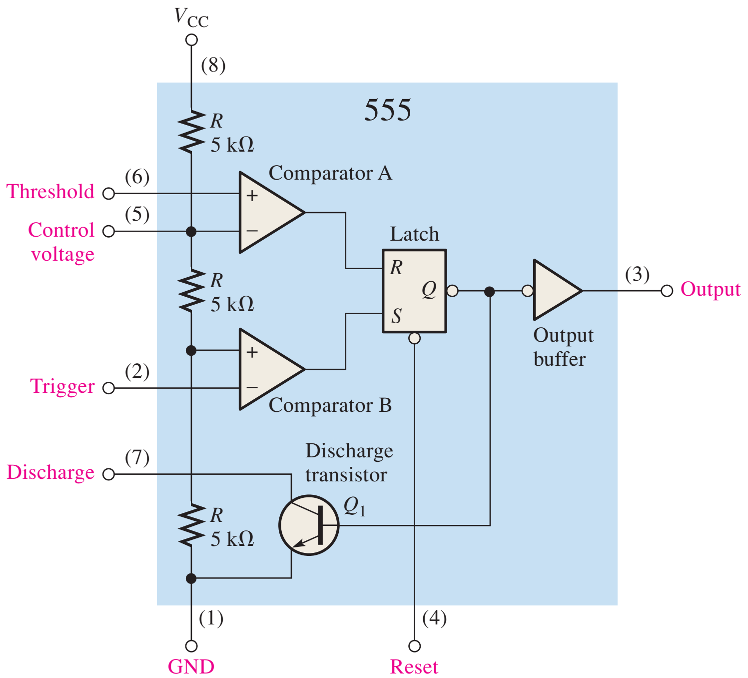



**FIGURE 7–52** Internal functional diagram of a 555 timer (pin numbers are in parentheses).

## Monostable (One-Shot) Operation

An external resistor and capacitor connected as shown in Figure 7–53 are used to set up the 555 timer as a nonretriggerable one-shot. The pulse width of the output is determined by the time constant of $R_1$ and $C_1$ according to the following formula:

$$t_W = 1.1R_1C_1 \qquad \text{Equation 7–3}$$

The control voltage input is not used and is connected to a decoupling capacitor $C_2$ to prevent noise from affecting the trigger and threshold levels.

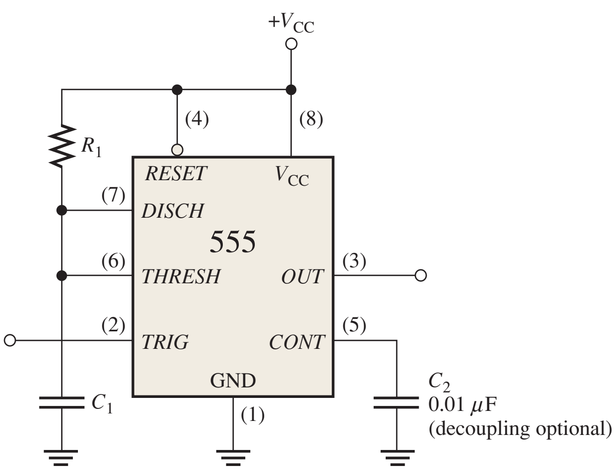



**FIGURE 7–53** The 555 timer connected as a one-shot.

Before a trigger pulse is applied, the output is LOW and the discharge transistor $Q_1$ is *on,* keeping $C_1$ discharged as shown in Figure 7–54(a). When a negative-going trigger pulse is applied at $t_0$, the output goes HIGH and the discharge transistor turns *off*, allowing capacitor $C_1$ to begin charging through $R_1$ as shown in part (b). When $C_1$ charges to $^1/_3\ V_{CC}$, the output goes back LOW at $t_1$ and $Q_1$ turns *on* immediately, discharging $C_1$ as shown in part (c). As you can see, the charging rate of $C_1$ determines how long the output is HIGH.

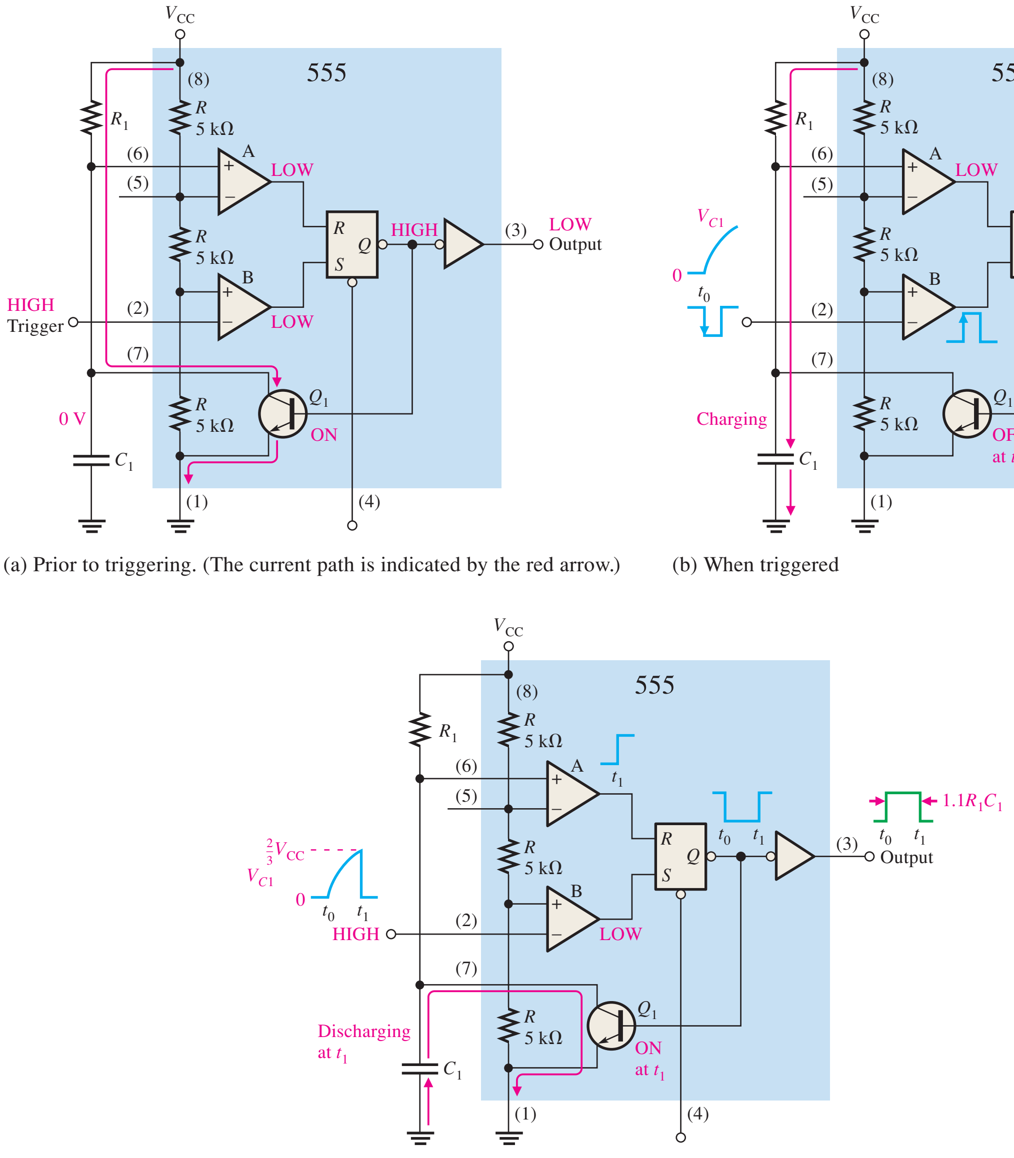



**FIGURE 7–54** One-shot operation of the 555 timer.

## EXAMPLE 7–13

What is the output pulse width for a 555 monostable circuit with $R_1 = 2.2\ \text{k}\Omega$ and $C_1 = 0.01\ \mu\text{F}$?

### Solution

From Equation 7–3 the pulse width is

$$t_W = 1.1R_1C_1 = 1.1(2.2\ \text{k}\Omega)(0.01\ \mu\text{F}) = \mathbf{24.2\ \mu s}$$

### Related Problem

For $C_1 = 0.01\ \mu\text{F}$, determine the value of $R_1$ for a pulse width of 1 ms.

## One-Shot with VHDL

An example of a VHDL program code for a one-shot is as follows:

```
library ieee;
use ieee.std_logic_1164.all;

entity OneShot is
  port (Enable, Clk: in std_logic;
        Duration: in integer range 0 to 25;
        QOut: buffer std_logic);
end entity OneShot;

architecture OneShotBehavior of OneShot is
begin
  Counter: process (Enable, Clk, Duration)
  variable Flag       : boolean := true;
  variable Cnt        : integer range 0 to 25;
  variable SetCount : integer range 0 to 25;
  begin
      SetCount := Duration;
      if (Clk'EVENT and Clk = '1') then
      if Enable = '0' then
            Flag := true;
         end if;

         if Enable = '1' and Flag then
         Cnt := 1;
             Flag :=False;
      end if;

         if cnt = SetCount then
        Qout <= '0';
             Cnt := 0;
                 Flag := false;
      else
             if Cnt > 0 then
             Cnt := Cnt + 1;
                 Qout <= '1';
         end if;
           end if;
      end if;
  end process;
end architecture OneShotBehavior;
```

**HandsOnTip**

In normal operation, a one-shot produces only a single pulse, which can be difficult to measure on an oscilloscope because the pulse does not occur regularly. To obtain a stable display for test purposes, it is useful to trigger the one-shot from a pulse generator that is set to a longer period than the expected pulse width and trigger the oscilloscope from the same pulse. For very long pulses, either store the waveform using a digital storage oscilloscope or shorten the time constant by some known factor. For example, replace a 1000 $\mu$F capacitor with a 1 $\mu$F capacitor to shorten the time by a factor of 1000. A faster pulse is easier to see and measure with an oscilloscope.

**SECTION 7–5 CHECKUP**

1. Describe the difference between a nonretriggerable and a retriggerable one-shot.
2. How is the output pulse width set in most IC one-shots?
3. What is the pulse width of a 555 timer one-shot when $C = 1\ \mu F$ and $R = 10\ k\Omega$?

## 7–6 The Astable Multivibrator

An **astable** multivibrator is a device that has no stable states; it changes back and forth (oscillates) between two unstable states without any external triggering. The resulting output is typically a square wave that is used as a clock signal in many types of sequential logic circuits. Astable multivibrators are also known as pulse **oscillators**.

After completing this section, you should be able to

- Describe the operation of a simple astable multivibrator using a Schmitt trigger circuit.
- Set up a 555 timer as an astable multivibrator.

Figure 7–55(a) shows a simple form of astable multivibrator using an inverter with hysteresis (Schmitt trigger) and an *RC* circuit connected in a feedback arrangement. When power is first applied, the capacitor has no charge; so the input to the Schmitt trigger inverter is LOW and the output is HIGH. The capacitor charges through *R* until the inverter input voltage reaches the upper trigger point (UTP), as shown in Figure 7–55(b). At this point, the inverter output goes LOW, causing the capacitor to discharge back through *R*, shown in part (b). When the inverter input voltage decreases to the lower trigger point (LTP), its output goes HIGH and the capacitor charges again. This charging/discharging cycle continues to repeat as long as power is applied to the circuit, and the resulting output is a pulse waveform, as indicated.

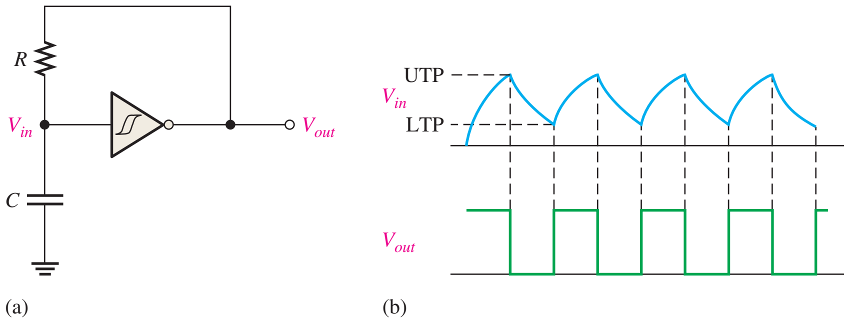



**FIGURE 7–55** Basic astable multivibrator using a Schmitt trigger.

**InfoNote**

Most systems require a timing source to provide accurate clock waveforms. The timing section controls all system timing and is responsible for the proper operation of the system hardware. The timing section usually consists of a crystal-controlled oscillator and counters for frequency division. Using a high-frequency oscillator divided down to a lower frequency provides for greater accuracy and frequency stability.

### The 555 Timer as an Astable Multivibrator

A 555 timer connected to operate as an astable multivibrator is shown in Figure 7–56. Notice that the threshold input (*THRESH*) is now connected to the trigger input (*TRIG*). The external components $R_1$, $R_2$, and $C_1$ form the timing network that sets the frequency of oscillation. The 0.01 $\mu$F capacitor, $C_2$, connected to the control (*CONT*) input is strictly for decoupling and has no effect on the operation; in some cases it can be left off.

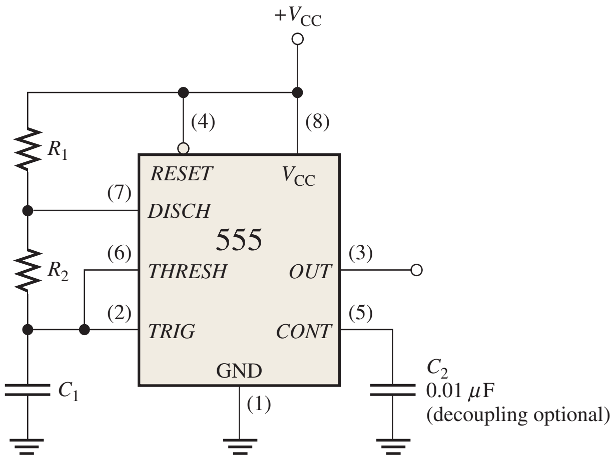



**FIGURE 7–56** The 555 timer connected as an astable multivibrator (oscillator).

Initially, when the power is turned on, the capacitor ($C_1$) is uncharged and thus the trigger voltage (pin 2) is at 0 V. This causes the output of comparator B to be HIGH and the output of comparator A to be LOW, forcing the output of the latch, and thus the base of $Q_1$, LOW and keeping the transistor off. Now, $C_1$ begins charging through $R_1$ and $R_2$, as indicated in Figure 7–57. When the capacitor voltage reaches $^1/_3\,V_{CC}$, comparator B switches to its LOW output state; and when the capacitor voltage reaches $^2/_3\,V_{CC}$, comparator A switches to its HIGH output state. This resets the latch, causing the base of $Q_1$ to go HIGH and turning on the transistor. This sequence creates a discharge path for the capacitor through $R_2$ and the transistor, as indicated. The capacitor now begins to discharge, causing comparator A to go LOW. At the point where the capacitor discharges down to $^1/_3\,V_{CC}$, comparator B switches HIGH; this sets the latch, making the base of $Q_1$ LOW and turning off the transistor. Another charging cycle begins, and the entire process repeats. The

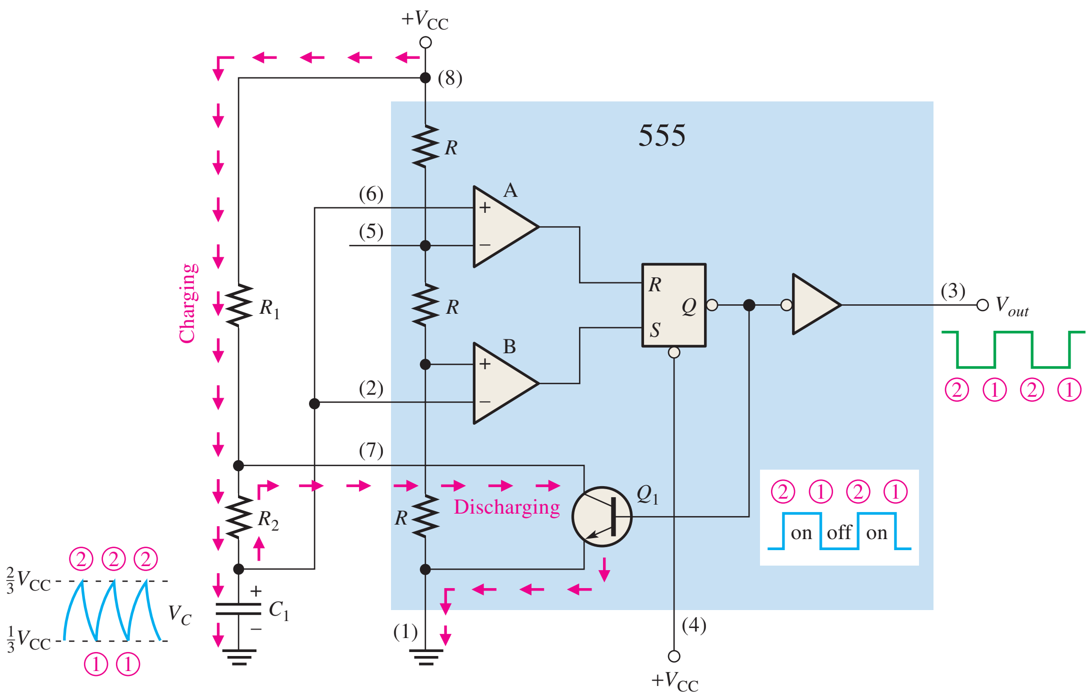



**FIGURE 7–57** Operation of the 555 timer in the astable mode.

result is a rectangular wave output whose duty cycle depends on the values of $R_1$ and $R_2$. The frequency of oscillation is given by the following formula, or it can be found using the graph in Figure 7–58.

$$\mathbf{f = \frac{1.44}{(R_1 + 2R_2)C_1}} \qquad \text{Equation 7–4}$$

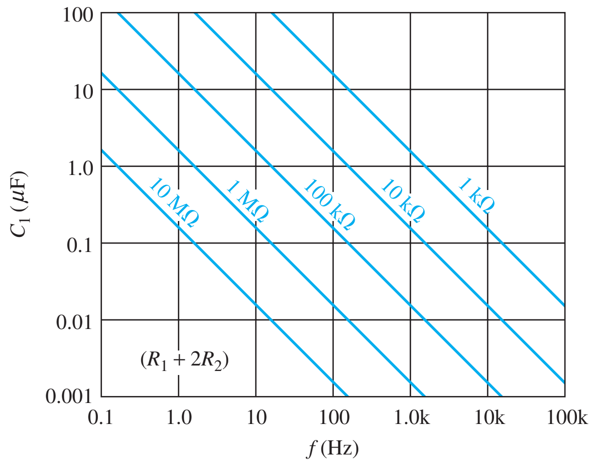



**FIGURE 7–58** Frequency of oscillation as a function of $C_1$ and $R_1 + 2R_2$. The sloped lines are values of $R_1 + 2R_2$.

By selecting $R_1$ and $R_2$, the duty cycle of the output can be adjusted. Since $C_1$ charges through $R_1 + R_2$ and discharges only through $R_2$, duty cycles approaching a minimum of 50 percent can be achieved if $R_2 \gg R_1$ so that the charging and discharging times are approximately equal.

An expression for the duty cycle is developed as follows. The time that the output is HIGH ($t_H$) is how long it takes $C_1$ to charge from $^1/_3\,V_{CC}$ to $^2/_3\,V_{CC}$. It is expressed as

$$\mathbf{t_H = 0.7(R_1 + R_2)C_1} \qquad \text{Equation 7–5}$$

The time that the output is LOW ($t_L$) is how long it takes $C_1$ to discharge from $^1/_3\,V_{CC}$ to $^2/_3\,V_{CC}$. It is expressed as

$$\mathbf{t_L = 0.7R_2C_1} \qquad \text{Equation 7–6}$$

The period, $T$, of the output waveform is the sum of $t_H$ and $t_L$. This is the reciprocal of $f$ in Equation 7–4.

$$T = t_H + t_L = 0.7(R_1 + 2R_2)C_1$$

Finally, the duty cycle is

$$\text{Duty cycle} = \frac{t_H}{T} = \frac{t_H}{t_H + t_L}$$

$$\textbf{Duty cycle} = \left(\frac{\mathbf{R_1 + R_2}}{\mathbf{R_1 + 2R_2}}\right)\mathbf{100\%} \qquad \text{Equation 7–7}$$

To achieve duty cycles of less than 50 percent, the circuit in Figure 7–56 can be modified so that $C_1$ charges through only $R_1$ and discharges through $R_2$. This is achieved with a diode, $D_1$, placed as shown in Figure 7–59. The duty cycle can be made less than 50 percent by making $R_1$ less than $R_2$. Under this condition, the expression for the duty cycle is

$$\textbf{Duty cycle} = \left(\frac{\mathbf{R_1}}{\mathbf{R_1 + R_2}}\right)\mathbf{100\%} \qquad \text{Equation 7–8}$$

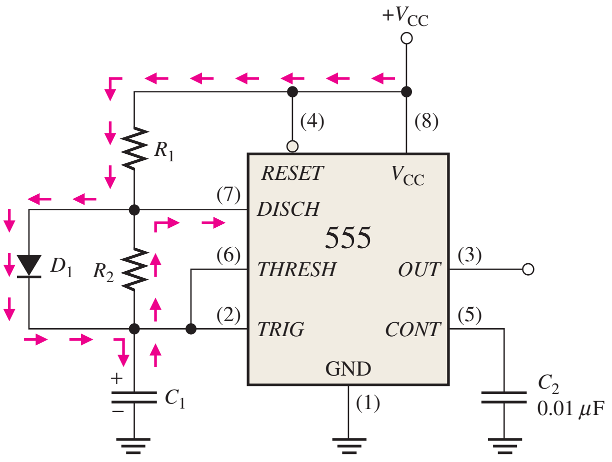



**FIGURE 7–59** The addition of diode $D_1$ allows the duty cycle of the output to be adjusted to less than 50 percent by making $R_1 < R_2$.

## EXAMPLE 7–14

A 555 timer configured to run in the astable mode (pulse oscillator) is shown in Figure 7–60. Determine the frequency of the output and the duty cycle.

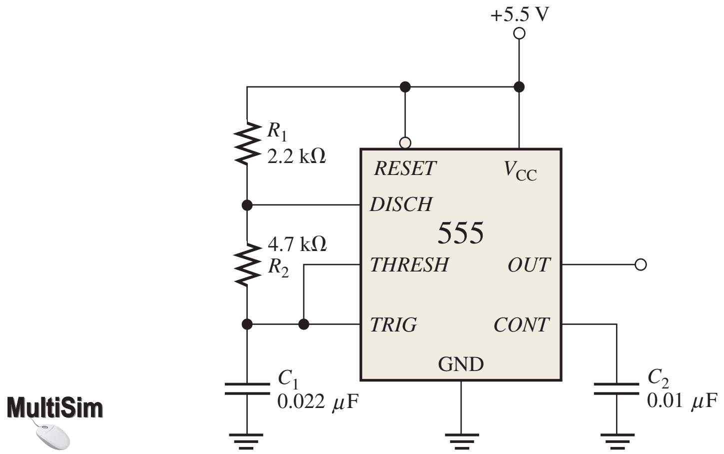



**FIGURE 7–60** Open file F07-60 to verify operation.

### Solution

Use Equations 7–4 and 7–7.

$$f = \frac{1.44}{(R_1 + 2R_2)C_1} = \frac{1.44}{(2.2\text{ k}\Omega + 9.4\text{ k}\Omega)0.022\ \mu\text{F}} = \mathbf{5.64\ kHz}$$

$$\text{Duty cycle} = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)100\% = \left(\frac{2.2\text{ k}\Omega + 4.7\text{ k}\Omega}{2.2\text{ k}\Omega + 9.4\text{ k}\Omega}\right)100\% = \mathbf{59.5\%}$$

### Related Problem

Determine the duty cycle in Figure 7–60 if a diode is connected across $R_2$ as indicated in Figure 7–59.