14.2 How do we use the 555 timer IC to perform timing functions?

Learning Outcomes

- Distinguish between a monostable and astable multivibrator.
- Identify the pins of a 555 timer IC from its specification sheet.
- Recognise whether a 555 timer IC is set up as a monostable or astable multivibrator from a given circuit (students are not required to draw the set-up).
- Use the formula $T = 1.1RC$ to determine the time period of a 555 timer IC in monostable mode (formula will be provided).
- Use the formula $T = \frac{(R_1 + 2R_2)C}{1.44}$ to determine the time period of a 555 timer IC in astable mode (formula will be provided).
- Draw the output timing diagram of a 555 timer IC.

Key Ideas

- A monostable multivibrator produces a single pulse of a specific width when triggered by an external input.
- An astable multivibrator produces a continuous stream of pulses (rectangular waveform).
- A 555 timer IC can be connected to operate as a monostable or an astable multivibrator.

There are two types of timing activities we often come across in our daily lives:

- One-off events that last for a fixed duration after being activated, e.g., a machine that runs for five minutes after a button is pressed and then stops until the button is pressed again
- Events that continue non-stop in a fixed timing pattern, e.g., traffic light signals

Both of these timing activities can be carried out by using a timer IC such as the 555 timer IC.

555 timer IC

The **555 timer IC** is a widely used device due to its low price and ease of use. Figure 14.15 shows a 555 timer IC in an 8-pin DIL packaging and its pin connection diagram.

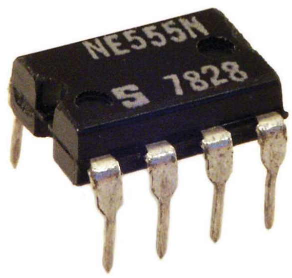


Figure 14.15a A 555 timer IC in a DIL packaging

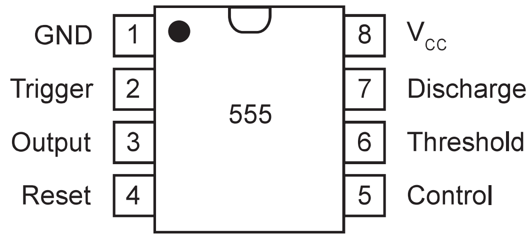


Figure 14.15b Pin connection diagram of a 555 timer IC

Table 14.2 describes the pin functions of the 555 timer IC and how they should be connected.

Table 14.2 Pin functions of the 555 timer IC

Pin	Name	Function
1	GND	Connects to 0 V (ground)
2	Trigger	Causes the output at pin 3 to go HIGH and starts the timing cycle when its voltage drops below $\frac{1}{3}V_{CC}$
3	Output	Produces a digital output: LOW (close to 0 V) or HIGH ($\approx V_{CC} - 1.5$ V)
4	Reset	Resets the timing interval when connected to the ground The timer will not start again until triggered by pin 2. When not in use, this pin is connected to V_{CC}.
5	Control	Controls the trigger and threshold level In most basic applications, this pin is not used and is connected to the ground through a 10 nF capacitor.
6	Threshold	Monitors the voltage across the external capacitor When the voltage at this pin reaches $\frac{2}{3}V_{CC}$, the timing cycle ends and the output on pin 3 goes LOW.
7	Discharge	Connects to the ground and discharges the external capacitor connected to it when the output is LOW and acts like an open circuit when the output is HIGH
8	V_{CC}	Connected to a positive voltage supply between 5 V and 15 V

The 555 timer IC is always connected to an external circuit. To make the overall circuit diagram logical and neat, a pin layout diagram shown in Figure 14.16 is used instead of the pin connection diagram. The supply voltage pin (V_{CC}) is at the top, the ground pin is at the bottom, the input pins are on the left and the output pin is on the right.

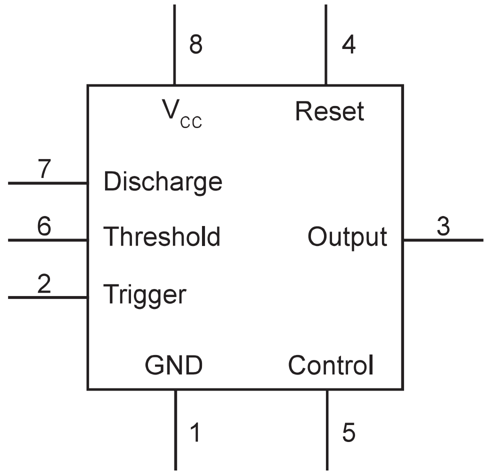


Figure 14.16 Pin layout diagram of 555 timer IC

The operation mode of the 555 timer IC depends on the external circuit that is connected to its input pins. In this course, we will learn how to connect the IC to work as a monostable and an astable multivibrator.

555 timer IC as a monostable multivibrator

A **monostable multivibrator** is a timing device that produces a single pulse of a specific width (in terms of time, not length) after being activated. The signal used for activating the multivibrator is called a 'trigger'. Figure 14.17 shows an example of such a single pulse, which can be used as a signal to control another device.

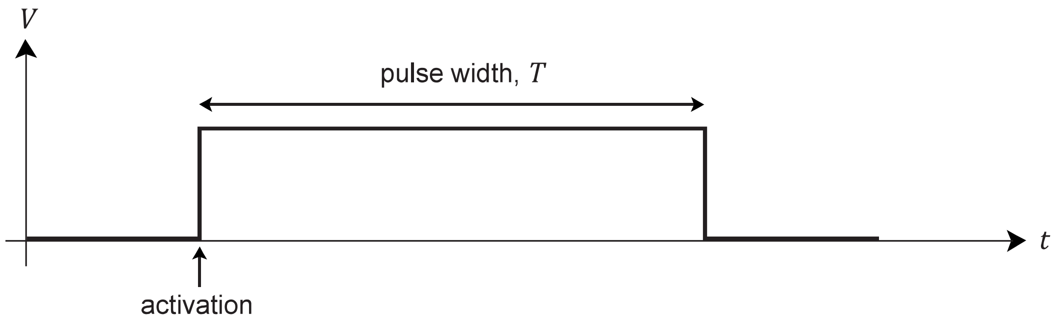


Figure 14.17 A monostable multivibrator produces a single pulse

Figure 14.18 shows how the 555 timer IC can be connected to work as a monostable multivibrator. Note the following:

- Pin 2 (trigger) is connected to a pull-up resistor and a pushbutton switch. When switch S is open, pin 2 is pulled up to V_{CC}. When switch S is closed by pushing it, pin 2 will become 0 V.
- Pins 6 and 7 are connected together. Both pins are then connected to an RC circuit formed by R_1 and C_1. The voltage across C_1 is equal to the voltage at both pins.

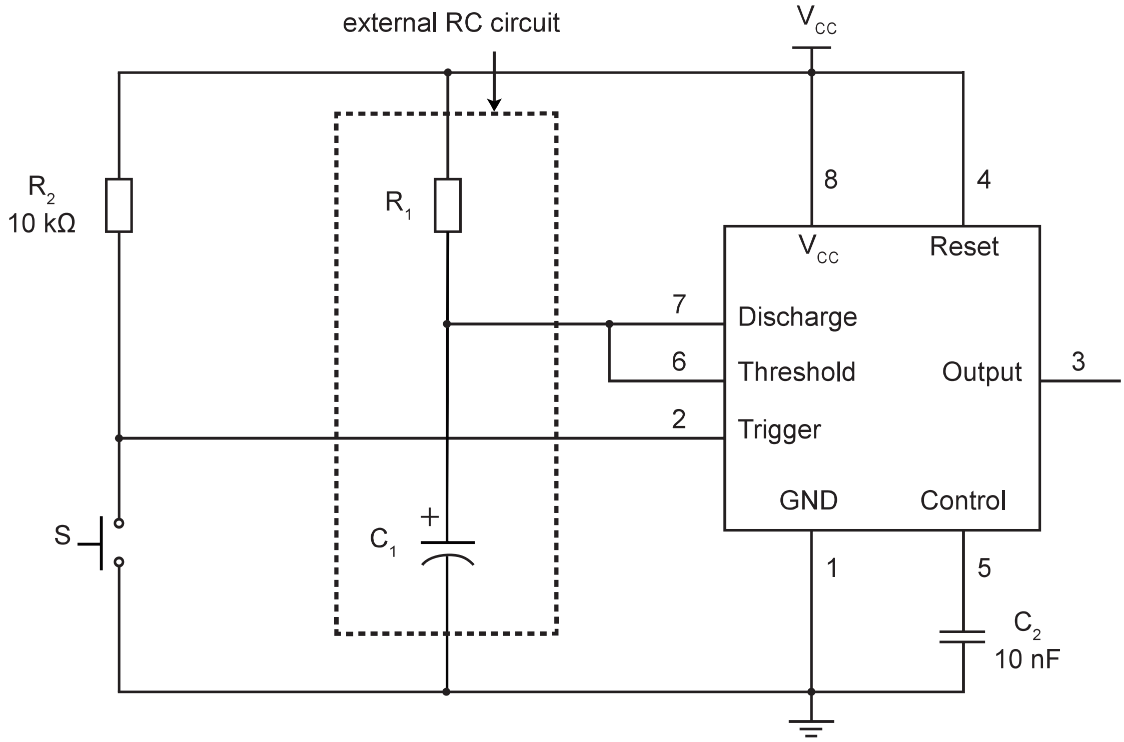


Figure 14.18 555 timer IC connected to operate as a monostable multivibrator

When a 555 timer IC is connected as a monostable multivibrator, the following occurs:

1. At the start, switch S is open, causing the voltage at pin 2 (trigger) to be pulled up to 5 V.
2. As pin 2 (trigger) is higher than $\frac{1}{3}V_{CC}$, the output is LOW. The IC connects pin 7 (discharge) to the ground, which completely discharges capacitor C_1.
3. When switch S is closed, the voltage at pin 2 (trigger) is pulled down to 0 V.
4. Since pin 2 (trigger) is lower than $\frac{1}{3}V_{CC}$, the output goes HIGH and the timing cycle starts. At the same time, the IC causes pin 7 (discharge) to act as an open circuit.
5. C_1 starts charging through R_1 towards V_{CC}.
6. When the voltage across C_1 reaches $\frac{2}{3}V_{CC}$, it will be detected by pin 6 (threshold).
7. The output goes LOW and the timing cycle stops.

Refer to Figure 14.19 for the timing diagram which shows how the voltages at pins 2, 3 and 6 change over time.

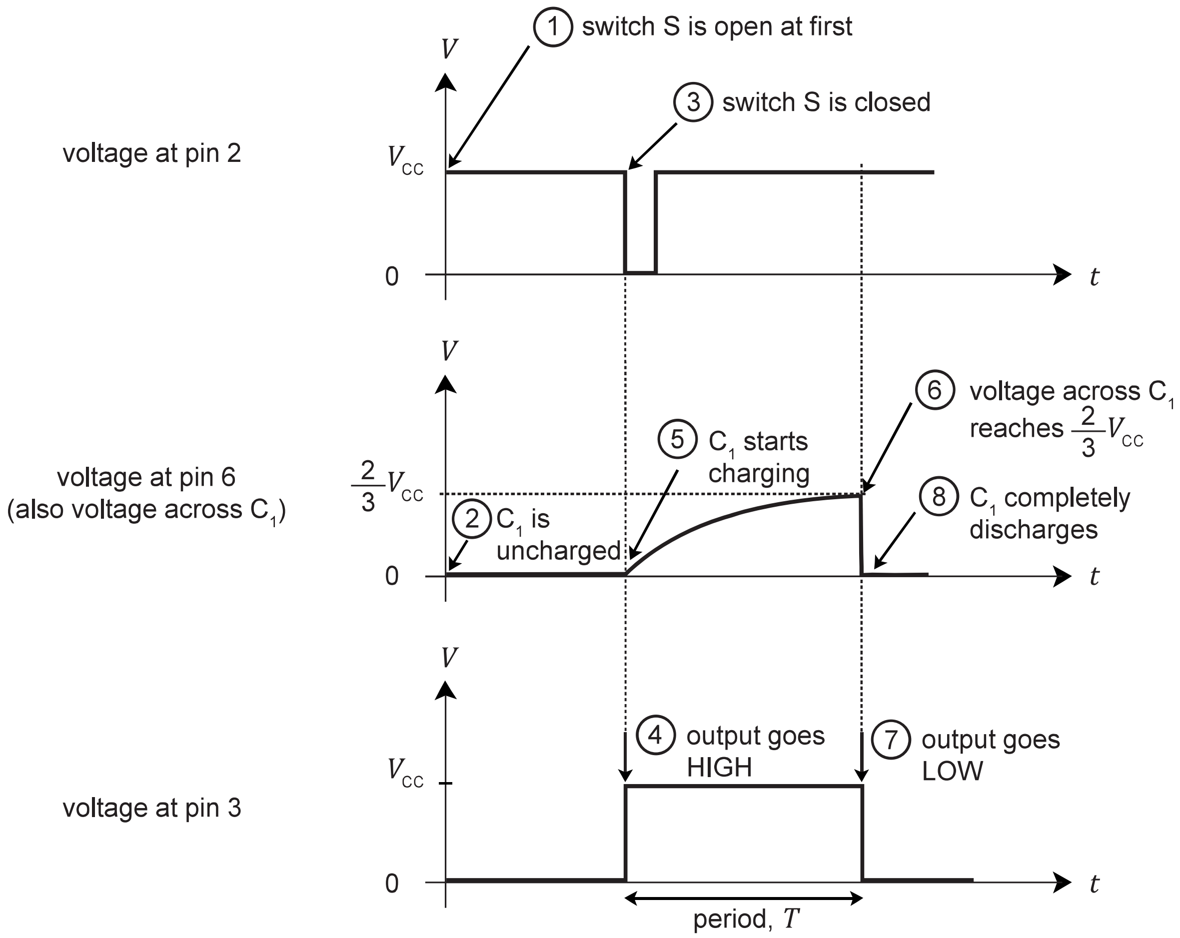


Figure 14.19 Timing diagram of a 555 timer IC operating as a monostable multivibrator

The pulse width of the output, T, is determined by the value of R_1 and C_1. It can be calculated using the following equation.

$$T = 1.1RC$$

where T = pulse width (in s),
R = resistance (in Ω),
C = capacitance (in F)

Note that R_2 is not part of the equation as it is simply acting as a pull-up resistor for switch S and is not involved in the charging process.

Worked Example 14.3

Refer to Figure 14.18. Given that R_1 = 5.6 kΩ, R_2 = 10 kΩ and C_1 = 47 μF, calculate the pulse width of the output when switch S is pushed.

Solution

Substitute R = 5.6 kΩ and C = 47 μF into the equation $T = 1.1RC$:

$$T = 1.1 \times (5.6 \times 10^3\ \Omega) \times (47 \times 10^{-6}\ \text{F})$$
$$= 0.290\ \text{s}$$
$$= 290\ \text{ms}$$

Worked Example 14.4

A student plans to use the monostable multivibrator circuit in Figure 14.18 to provide a single pulse of 45 s. Determine the values of R_1 and C_1 that should be used.

Solution

From Figure 14.19, we can see that the pulse width is approximately equal to the time taken for C_1 to charge to $\frac{2}{3}$ of the applied voltage. This corresponds to the time constant of an RC circuit. Refer to the circuit in Worked Example 6.4, which had a time constant of 22 ms with R = 2.2 kΩ and C = 10 μF.

Since 45 s is nearly 2000 times longer than 22 ms, we should choose a capacitor with much larger capacitance, e.g., 1000 μF.

Substituting T = 45 s and C = 1000 μF into $T = 1.1RC$,

$$45\ \text{s} = 1.1 \times R \times (1000 \times 10^{-6}\ \text{F})$$
$$R = 41\ \text{k}\Omega$$

We can use a 33 kΩ fixed resistor in series with a 0–10 kΩ variable resistor and adjust the variable resistor until their combined resistance is 41 kΩ.

Review Questions 14.2A

1. Complete Figure 14.20 to show how a 555 timer IC can be connected as a monostable multivibrator.

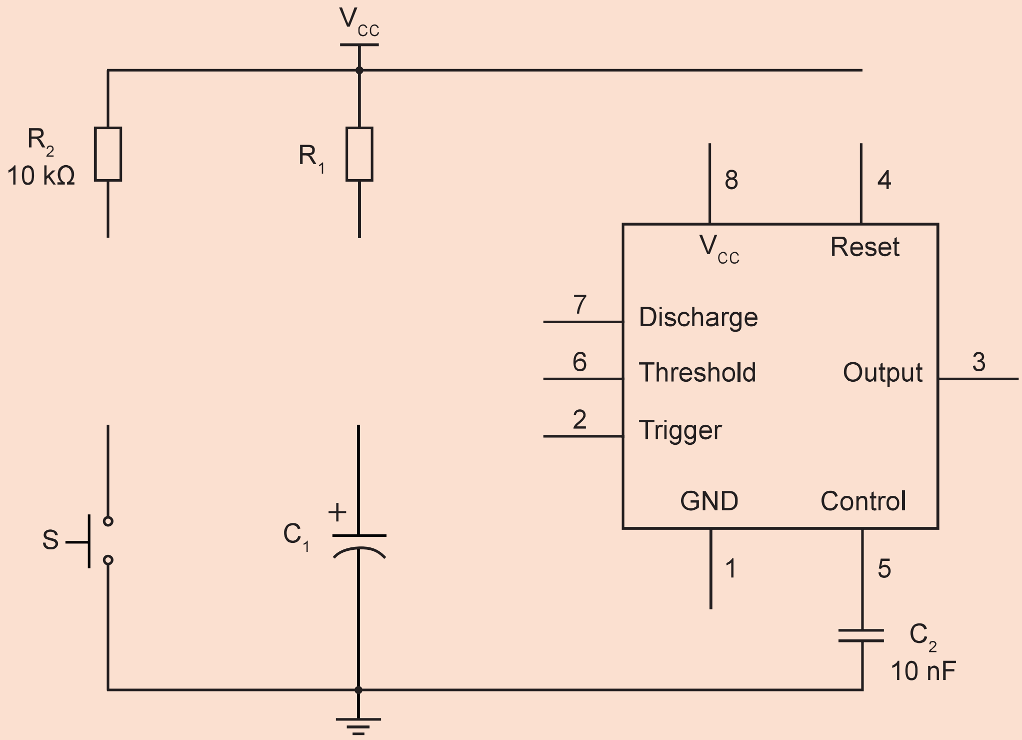


Figure 14.20

2. A student plans to use the monostable multivibrator circuit in Figure 14.18 to provide a single pulse with a width of 3.0 s. Determine the values of R_1 and C_1 that should be used.

555 timer IC as an astable multivibrator

An **astable multivibrator** is a timing device that produces a continuous stream of pulses (rectangular waveforms). Unlike the monostable multivibrator, there is no trigger. Figure 14.21 shows an example of pulses produced by an astable multivibrator. Such pulses are useful for producing flashing lights and as a clock signal for a counter IC (see Section 14.3).

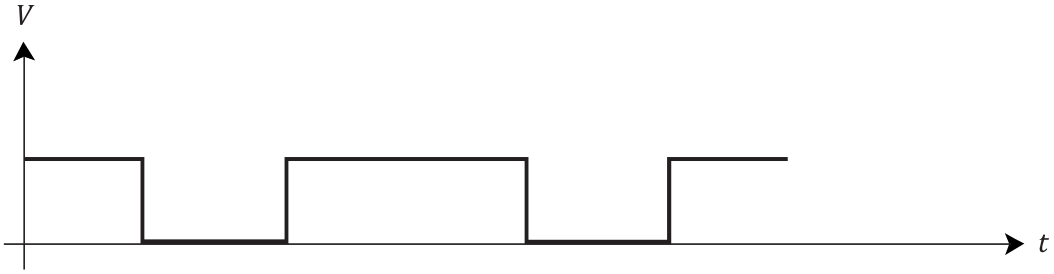


Figure 14.21 An astable multivibrator produces a continuous stream of pulses

Figure 14.22 shows how the 555 timer IC can be connected to work as an astable multivibrator. Like the monostable multivibrator, the external circuit is an RC circuit. However, notice that it is pin 2 (trigger) and pin 6 (threshold) that are connected together. Both pins are connected to capacitor C_1 such that the voltage across C_1 is equal to the voltage at pins 2 and 6.

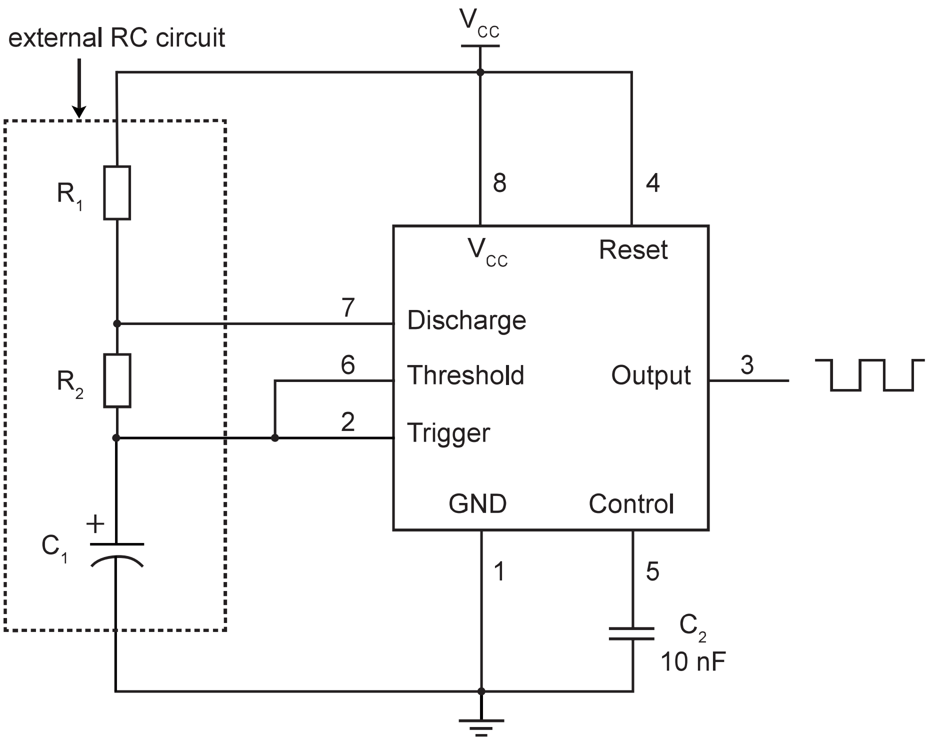


Figure 14.22 Connecting a 555 timer IC as an astable multivibrator

When a 555 timer IC is used as an astable multivibrator, the following occurs:

1. At the start, assume that C_1 is not charged. Hence, the voltage at pin 2 (trigger) is 0 V.
2. As pin 2 is lower than $\frac{1}{3}V_{CC}$, the output will be HIGH, which causes pin 7 (discharge) to act as an open circuit. C_1 then starts charging through R_1 and R_2 towards V_{CC}.
3. C_1 continues to charge until the voltage across it, which is also the voltage at pin 6 (threshold), reaches $\frac{2}{3}V_{CC}$.
4. The output goes LOW. The IC then connects pin 7 to the ground, causing C_1 to start discharging through R_2.
5. C_1 continues to discharge until the voltage across it decreases to $\frac{1}{3}V_{CC}$.
6. The output at pin 3 goes HIGH again and the process repeats itself.

Refer to Figure 14.23 for the timing diagram which shows how the voltages at pins 2, 3 and 6 change over time.

The first output cycle should be ignored as it is dependent on how much charge C_1 holds at the start. Figure 14.23 assumes that C_1 is uncharged. If C_1 holds some charge at the start, then the cycle will either start in the same manner (if the voltage across C_1 is less than $\frac{1}{3}V_{CC}$) or after step 4 (if the voltage across C_1 is more than $\frac{1}{3}V_{CC}$).

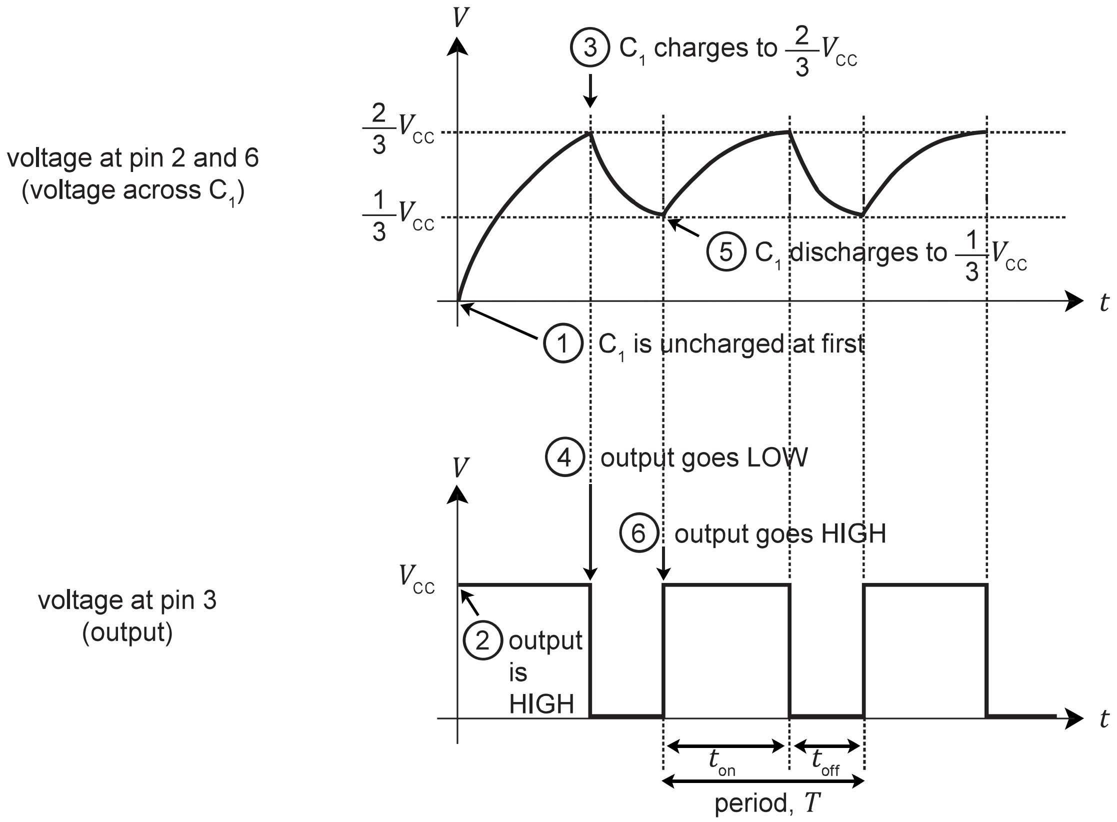


Figure 14.23 Timing diagram of a 555 timer IC operating as an astable multivibrator

Notice that the output signal alternates between the HIGH and LOW states in a fixed timing pattern. The duration of the signal at the HIGH state is labelled as t_{on} since the HIGH state is commonly associated with a device being switched on. Conversely, the duration of the signal at the LOW state is called t_{off}. The period of a complete cycle is labelled as T, where $T = t_{on} + t_{off}$.

The duration of t_{on}, t_{off} and T are determined by the values of R_1, R_2 and C_1. They can be calculated using the following equations:

$$T = \frac{(R_1 + 2R_2)C}{1.44}$$

$$t_{on} = 0.7(R_1 + R_2)C$$

$$t_{off} = 0.7R_2C$$

where T = period (in s),
R = resistance (in Ω),
C = capacitance (in F)
t_{on} = duration in which output is HIGH (in s),
t_{off} = duration in which output is LOW (in s).

Recall that both R_1 and R_2 are involved during the charging of C_1, but only R_2 is involved in the discharging process. This explains why the equation for t_{on} involves both resistors while the equation for t_{off} only involves R_2.

The duty cycle and frequency of the pulses can be calculated using the following equations:

$$\text{Duty cycle} = \frac{t_{on}}{T} \times 100\%$$

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

where T = period (in s),
f = frequency (in Hz),
t_{on} = duration in which output is HIGH (in s).

Worked Example 14.5

Refer to the circuit shown in Figure 14.22. Given R_1 = 1.0 kΩ, R_2 = 10 kΩ and C_1 = 47 μF, calculate:

(a) the period of the output signal;

(b) the duty cycle of the output signal; and

(c) the frequency of the output signal.

Solution

(a) $T = \frac{(R_1 + 2R_2)C}{1.44}$

$= \frac{[(1.0 \times 10^3\ \Omega) + 2 \times (10 \times 10^3\ \Omega)] \times 47 \times 10^{-6}\ \text{F}}{1.44}$

$= 685$ ms

(b) $t_{on} = 0.7(R_1 + R_2)C$

$= 0.7 \times (1.0 \times 10^3\ \Omega + 2 \times 10 \times 10^3\ \Omega) \times 47 \times 10^{-6}$ F

$= 362$ ms

Duty cycle $= \frac{t_{on}}{T} \times 100\%$

$= \frac{362 \text{ ms}}{685 \text{ ms}} \times 100\%$

$= 52.8\%$

(c) Frequency, $t_{on} = \frac{1}{T}$

$= \frac{1}{685 \times 10^{-3}\ \text{s}}$

$= 1.46$ Hz

Extension

From the calculated values, we can draw the waveform of the output signal:

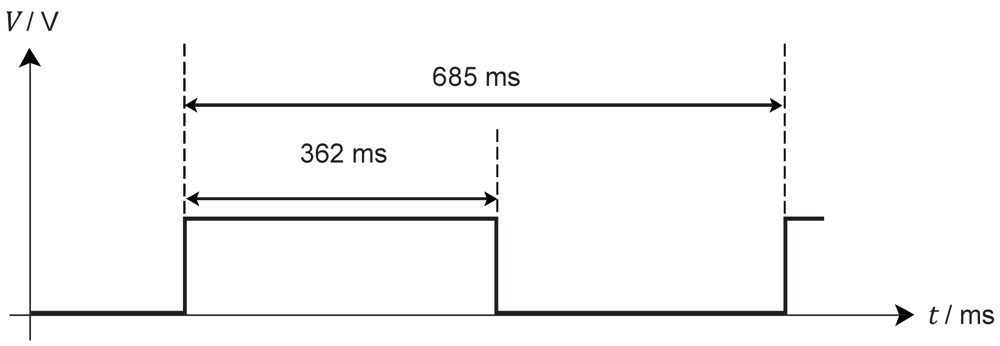
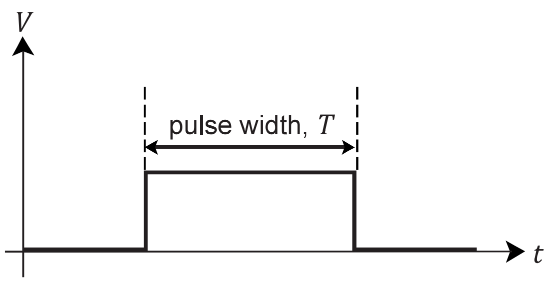
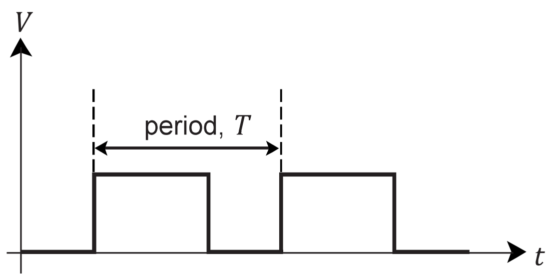


Figure 14.24

Table 14.3 summarises the differences between a monostable and an astable multivibrator built using a 555 timer IC.

Table 14.3 Comparing the monostable and astable multivibrator

Monostable multivibrator	Astable multivibrator
When triggered, a single rectangular pulse of a predetermined pulse width is produced. The pulse width is determined by a resistor and a capacitor that are externally connected to the 555 timer IC.	It produces a rectangular wave whose period is determined by two resistors and a capacitor that are externally connected to the 555 timer IC. This rectangular wave will be generated the moment the IC is powered up without the need for a trigger.
Output waveform: 	Output waveform: 
Commonly used in timers and debounced switches	Commonly used in LED flashers, logic clocks and tone generators

Review Questions 14.2B

1. Complete Figure 14.25 to show how a 555 timer IC can be connected to work as an astable multivibrator. Your answer should include all necessary components and connections. All inputs and outputs should be clearly labelled.

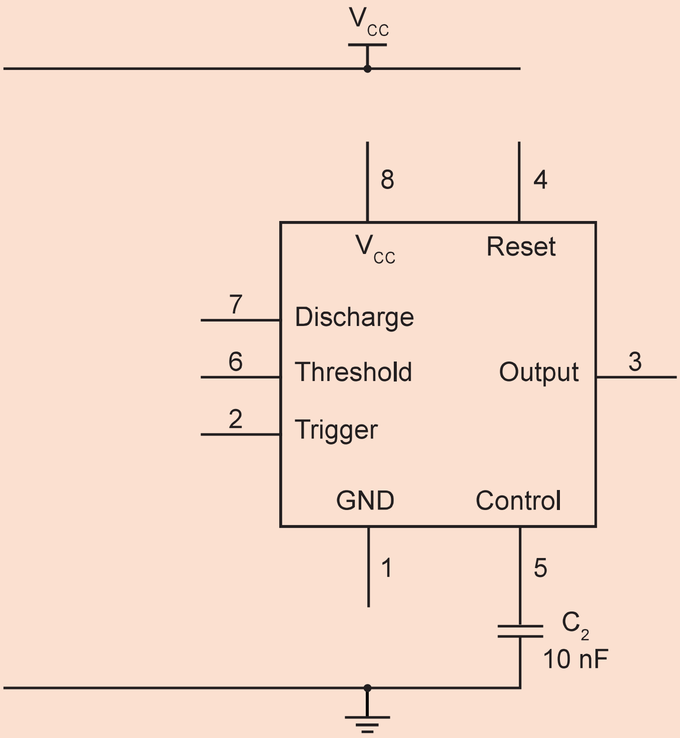


Figure 14.25

2. The 555 timer IC is connected to operate as an astable multivibrator as shown in Figure 14.26. Calculate the period of the output signal.

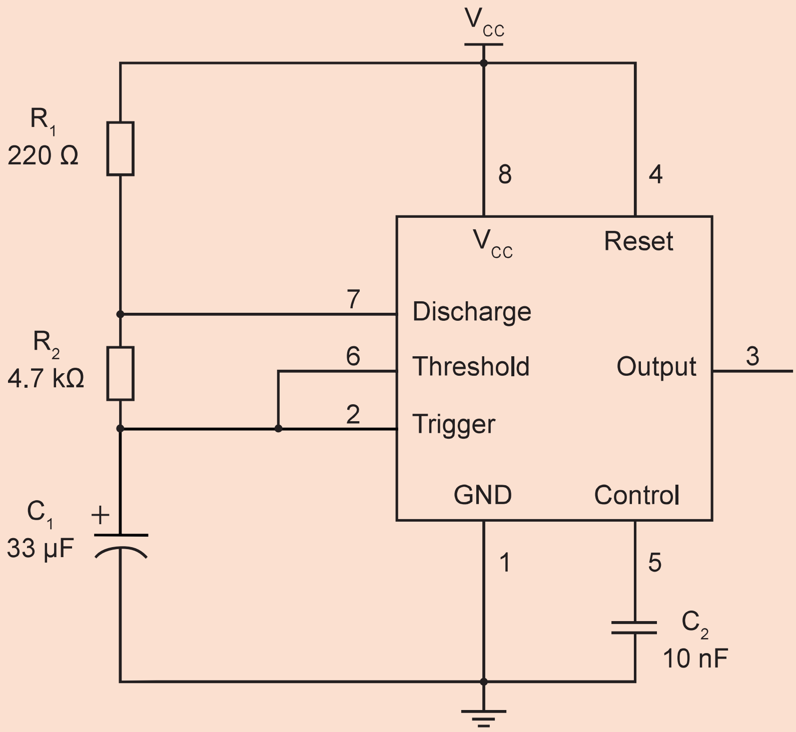


Figure 14.26

14.3 How do we use the 74LS390 decade counter IC to perform counting functions?

Learning Outcomes

- Identify the pins of a 74LS390 4-bit decade counter IC from its specification sheet.
- Describe the operation and use of a 74LS390 IC.
- Show understanding of how the output of a 74LS390 IC can be shown on a 7-segment display.
- Show understanding of how two 4-bit decade counters in a 74LS390 IC can be connected to count to 99.

Key Ideas

- A decade counter is a counter that counts from 0 to 9 and then returns to 0 again.
- The 74LS390 4-bit decade counter IC has two decade counters that can be used together to count up to 99.

Counting is an important application of electronics. In the introduction of this chapter, we saw how the electronic display at a carpark entrance informs drivers about the number of available parking lots. Another example is the banknote counting machines used by banks and money changers as shown in Figure 14.27. Digital clocks and stopwatches also use counters to count the seconds, minutes and hours that have passed.

Figure 14.27 Banknote counting machine