Digital System Design

Electrical Department-Fourth Stage

Lecture two

By

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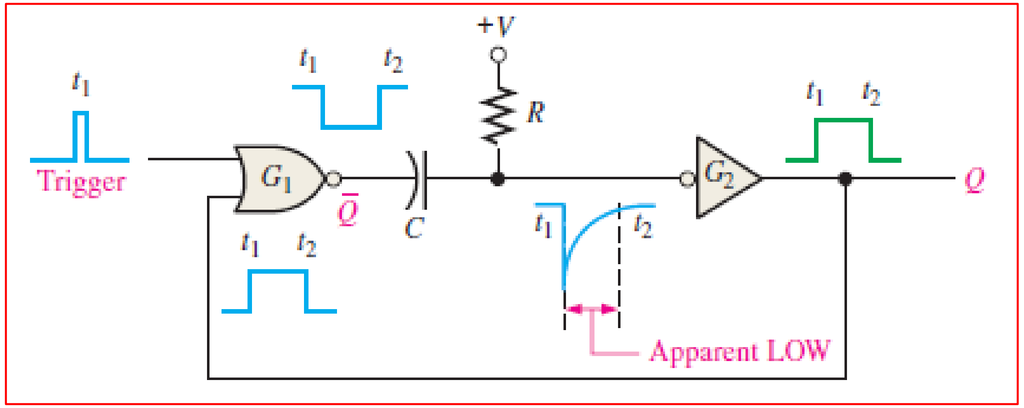
Timing Circuits

- **Monostable and A stable Multiviberators**

The monostable multivibrator- one-shot

- A monostable multivibrator, is a device with only one stable state. A one-shot is normally in its stable state and will change to its unstable state only when triggered.
- Once it is triggered, the one-shot remains in its unstable state for a predetermined length of time and then automatically returns to its stable state.



- The time that the device stays in its unstable state determines the pulse width of its output.

FIGURE 43 A simple one-shot circuit.

- Figure 43 shows a basic one-shot (monostable multivibrator) that is composed of a logic gate and an inverter. When a pulse is applied to the trigger input, the output of gate G1 goes LOW. This HIGH-to-LOW transition is coupled through the capacitor to the input of inverter G2.
- The apparent LOW on G2 makes its output go HIGH. This HIGH is connected back into G1, keeping its output LOW. Up to this point the trigger pulse has caused the output of the one-shot, Q, to go HIGH.
- The capacitor immediately begins to charge through R toward the high voltage level. The rate at which it charges is determined by the RC time constant. When the capacitor charges to a certain level, which appears as a HIGH to G2, the output goes back LOW.

- To summarize, the output of inverter G2 goes HIGH in response to the trigger input. It remains HIGH for a time set by the RC time constant. At the end of this time, it goes LOW. A single narrow trigger pulse produces a single output pulse whose time duration is controlled by the RC time constant. This operation is illustrated in Figure 43.
- A typical one-shot logic symbol is shown in Figure 44(a), and the same symbol with an external R and C is shown in Figure 44(b). The two basic types of IC one-shots are nonretriggerable and retriggerable.

- A nonretriggerable one-shot will not respond to any additional trigger pulses from the time it is triggered into its unstable state until it returns to its stable state. In other words, it will ignore any trigger pulses occurring before it times out.

- The time that the one-shot remains in its unstable state is the pulse width of the output.

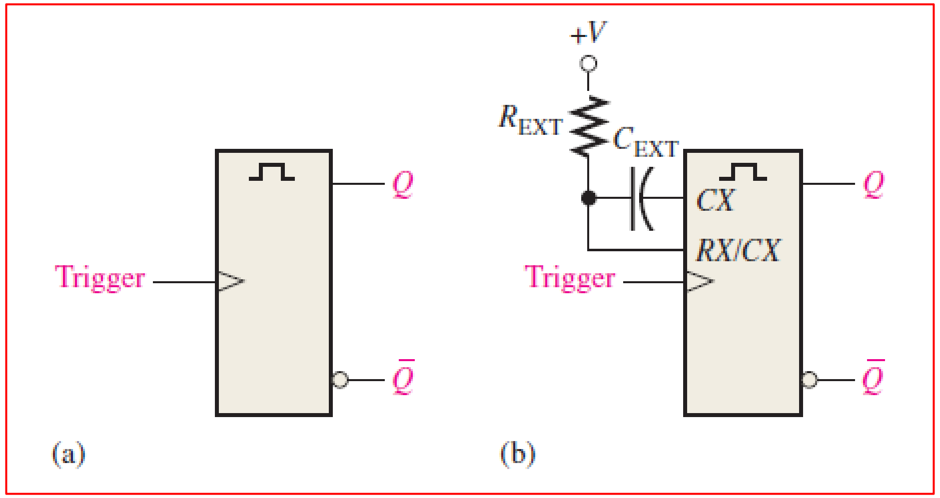


FIGURE 44 Basic one-shot logic symbols. CX and RX stand for external components.

- Figure 45 shows the nonretriggerable one-shot being triggered at intervals greater than its pulse width and at intervals less than the pulse width. Notice that in the second case, the additional pulses are ignored.

- A retriggerable one-shot can be triggered before it times out. The result of retriggering is an extension of the pulse width as illustrated in Figure 46.

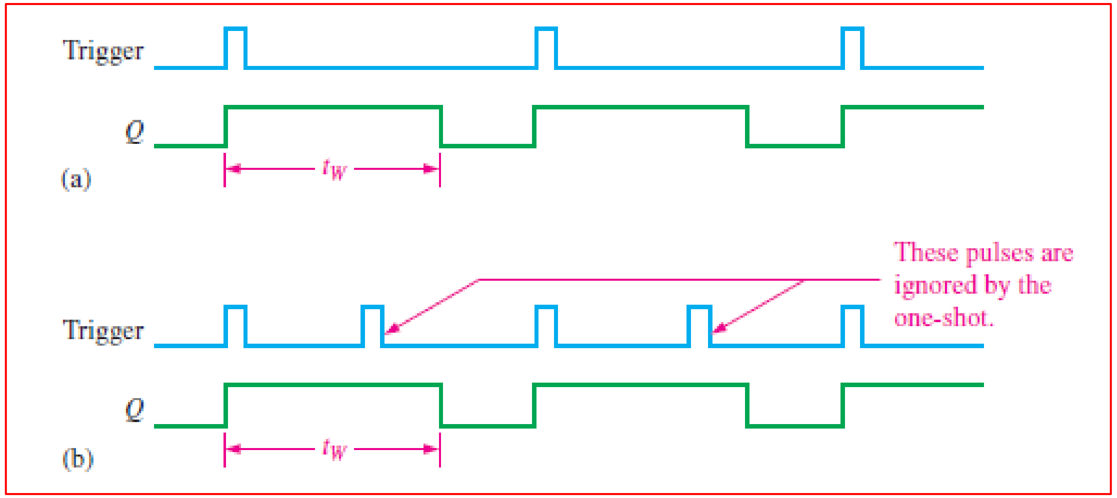


FIGURE 45 Nonretriggerable one-shot action.

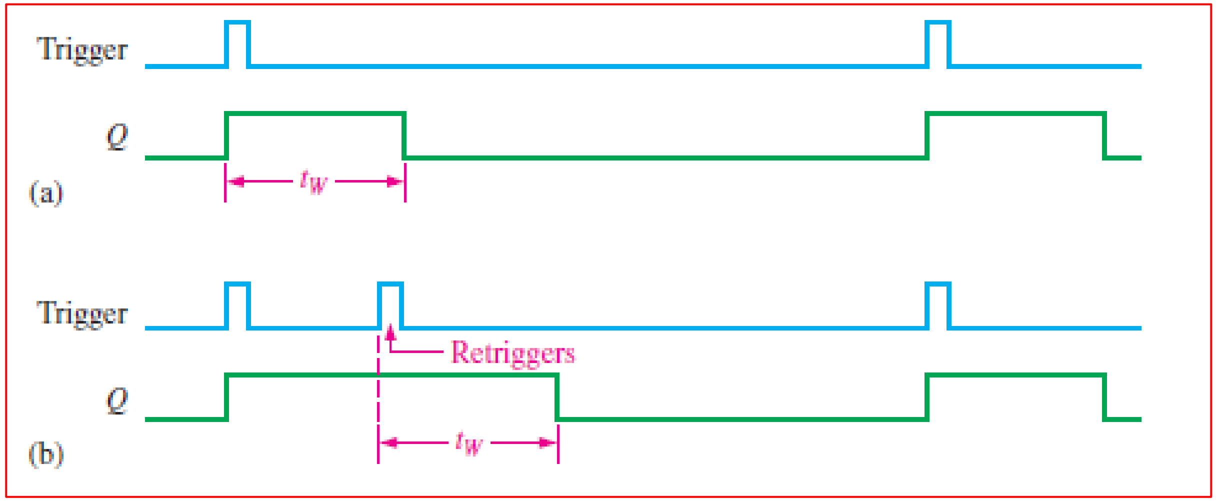


FIGURE 46 Retriggerable one-shot action.

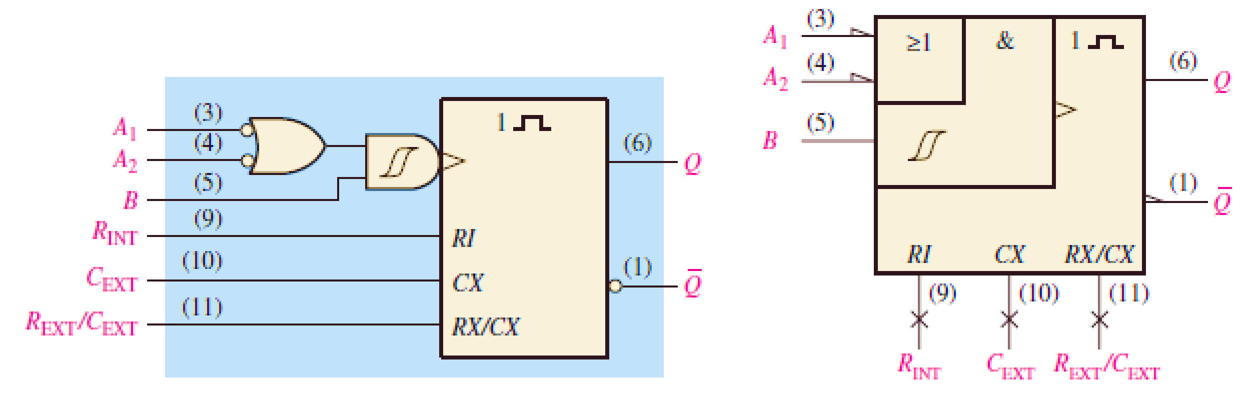
Nonretriggerable One-Shot

- The 74121 is an example of a nonretriggerable IC one-shot. It has provisions for external R and C, as shown in Figure 47.
- The inputs labeled A1, A2, and B are gated trigger inputs. The R_{INT} input connects to a 2 kΩ internal timing resistor.

Setting the Pulse Width

- A typical pulse width of about 30 ns is produced when no external timing components are used and the internal timing resistor (R_{INT}) is connected to VCC, as shown in Figure 48(a).

- The pulse width can be set anywhere between about 30 ns and 28 s by the use of external components.



(a) Traditional logic symbol

(b) ANSI/IEEE std. 91–1984 logic symbol (✕ = nonlogic connection). "1⎍" is the qualifying symbol for a nonretriggerable one-shot.

FIGURE 47 Logic symbols for the 74121 nonretriggerable one-shot.

- Figure 48(b) shows the configuration using the internal resistor (2 kΩ) and an external capacitor.
- Part (c) shows the configuration using an external resistor and an external capacitor.
- The output pulse width is set by the values of the resistor (R_{INT} = 2 kΩ, and R_{EXT} is selected) and the capacitor according to the following formula:

$$t_W = 0.7\,RC_{EXT} \qquad \text{Equation (1)}$$

where R is either R_{INT} or R_{EXT}. When R is in kilohms (k Ω) and C_{EXT} is in picofarads (pF), the output pulse width t_W is in nanoseconds (ns).

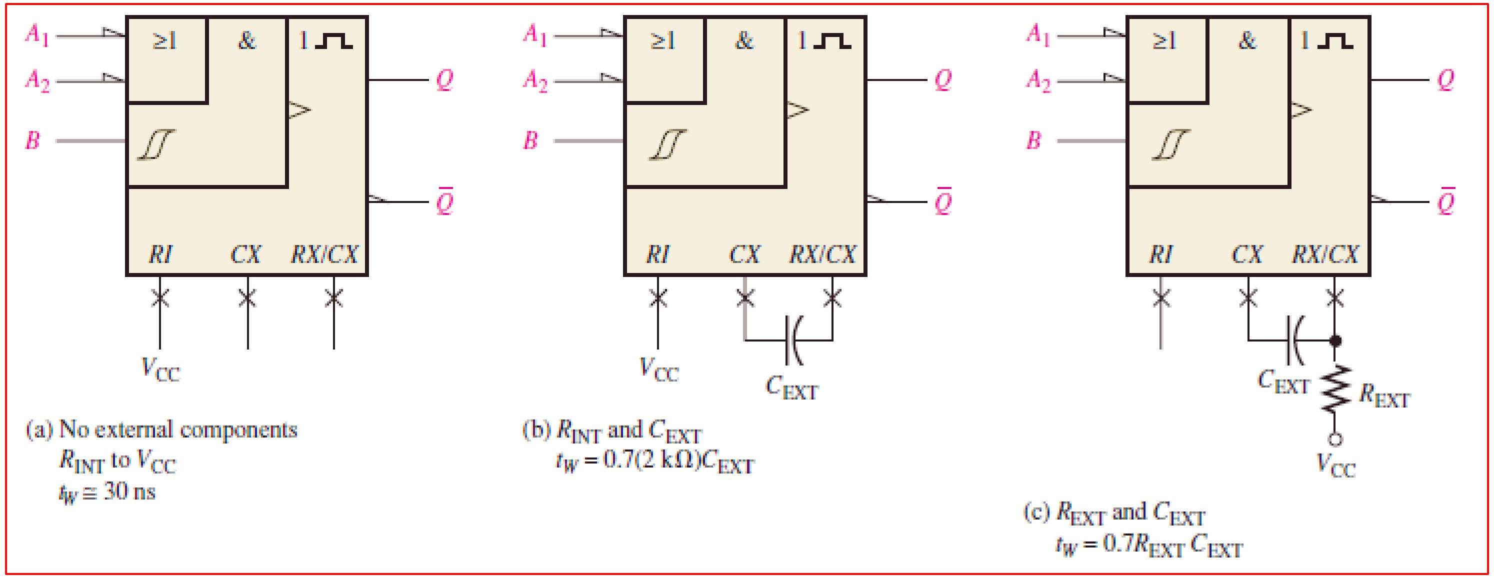


FIGURE 48 Three ways to set the pulse width of a 74121.

The Schmitt-Trigger Symbol

The symbol ⎎ indicates a Schmitt-trigger input. This type of input uses a special threshold circuit that produces **hysteresis**, a characteristic that prevents erratic switching between states when a slow-changing trigger voltage hovers around the critical input level. This allows reliable triggering to occur even when the input is changing as slowly as 1 volt/second.

Retriggerable One-Shot

- The 74LS122 is an example of a retriggerable IC one-shot with a clear input. It also has provisions for external *R* and *C*, as shown in Figure 49. The inputs labeled A_1, A_2, B_1, and B_2 are the gated trigger inputs.

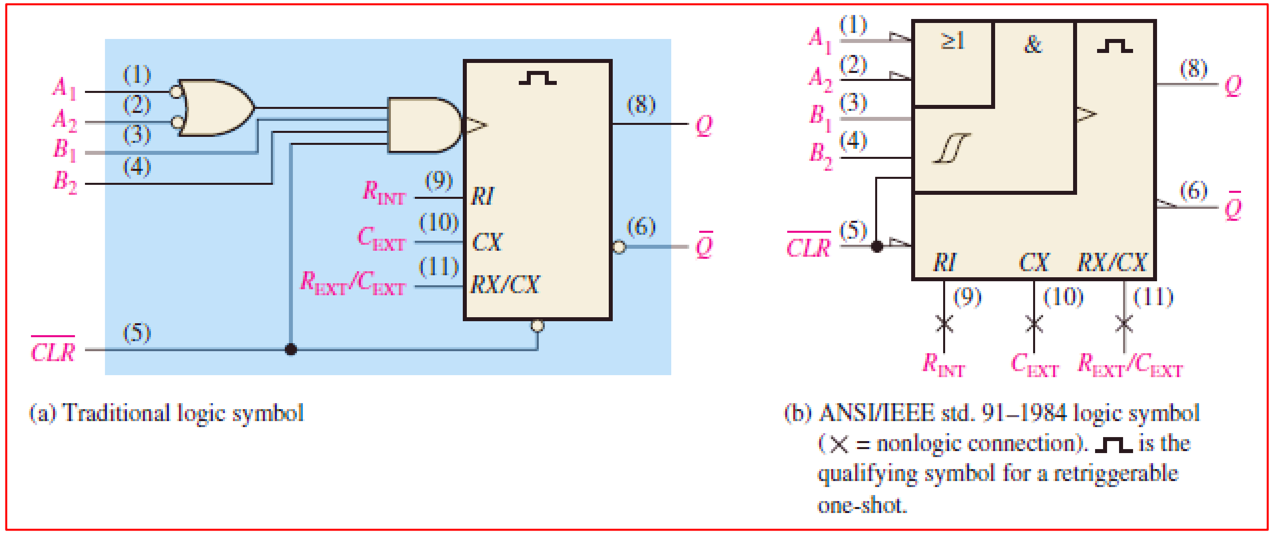


FIGURE 49 Logic symbol for the 74LS122 retriggerable one-shot.

- A minimum pulse width of approximately 45 ns is obtained with no external components. Wider pulse widths are achieved by using external components. A general formula for calculating the values of these components for a specified pulse width (t_W) is

$$t_W = 0.32RC\ C_{EXT}\ (1+\frac{0.7}{R}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq. 2$$

where 0.32 is a constant determined by the particular type of one-shot, R is in k Ω and is either the internal or the external resistor, C_{EXT} is in pF, and t_W is in ns. The internal resistance is 10 kΩ and can be used instead of an external resistor. (Notice the difference between this formula and that for the 74121, shown in Equation 1.)

EXAMPLE 7–11

A certain application requires a one-shot with a pulse width of approximately 100 ms. Using a 74121, show the connections and the component values.

Solution

Arbitrarily select $R_{EXT} = 39\text{ k}\Omega$ and calculate the necessary capacitance.

$$t_W = 0.7R_{EXT}C_{EXT}$$

$$C_{EXT} = \frac{t_W}{0.7R_{EXT}}$$

where C_{EXT} is in pF, R_{EXT} is in kΩ, and t_W is in ns. Since 100 ms $= 1 \times 10^8$ ns,

$$C_{EXT} = \frac{1 \times 10^8\text{ ns}}{0.7(39\text{ k}\Omega)} = 3.66 \times 10^{-6}\text{ pF} = \mathbf{3.66\ \mu F}$$

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A standard 3.3 μF capacitor will give an output pulse width of 91 ms. The proper connections are shown in Figure . -50. To achieve a pulse width closer to 100 ms, other combinations of values for R_{EXT} and C_{EXT} can be tried. For example, $R_{EXT} = 68$ kΩ and $C_{EXT} = 2.2$ μF gives a pulse width of 105 ms.

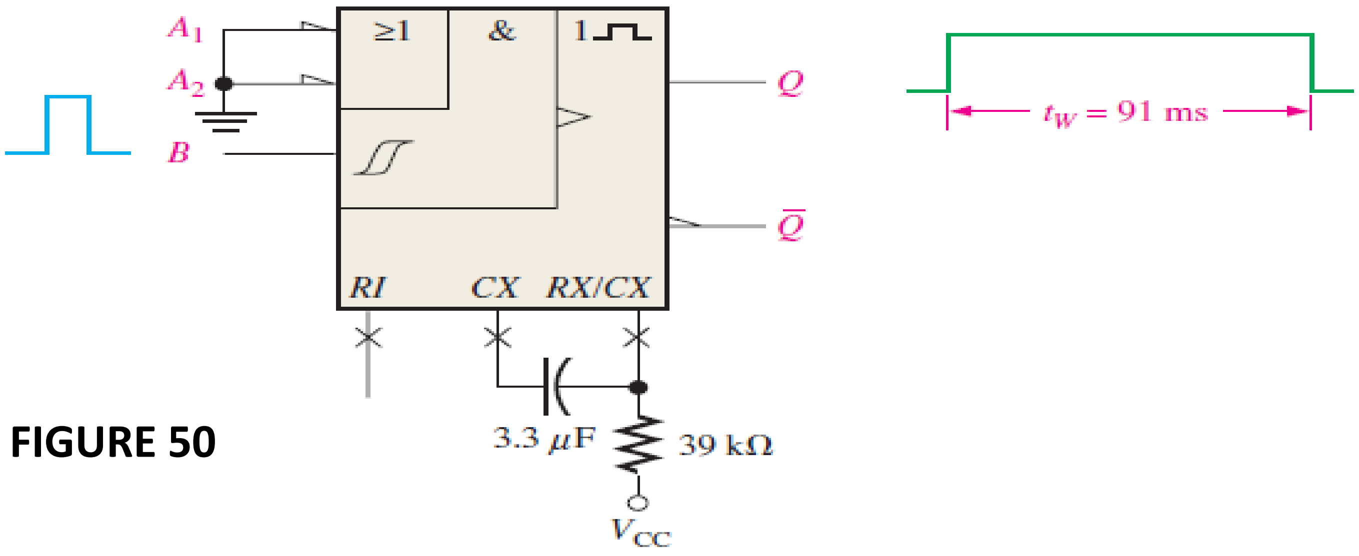


FIGURE 50

EXAMPLE 12

Determine the values of R_{EXT} and C_{EXT} that will produce a pulse width of 1 μs when connected to a 74LS122.

Solution

Assume a value of C_{EXT} = **560 pF** and then solve for R_{EXT}. The pulse width must be expressed in ns and C_{EXT} in pF. R_{EXT} will be in kΩ.

$$t_w = 0.32R_{EXT}C_{EXT}\left(1 + \frac{0.7}{R_{EXT}}\right) = 0.32R_{EXT}C_{EXT} + 0.7\left(\frac{0.32R_{EXT}C_{EXT}}{R_{EXT}}\right)$$

$$= 0.32R_{EXT}C_{EXT} + (0.7)(0.32)C_{EXT}$$

$$R_{EXT} = \frac{t_W - (0.7)(0.32)C_{EXT}}{0.32C_{EXT}} = \frac{t_W}{0.32C_{EXT}} - 0.7$$

$$= \frac{1000\text{ ns}}{(0.32)560\text{ pF}} - 0.7 = \mathbf{4.88\ k\Omega}$$

Use a standard value of **4.7 kΩ.**

Related Problem

Show the connections and component values for a 74LS122 one-shot with an output pulse width of 5 μs. Assume C_{EXT} = 560 pF.

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 555 Timer Operation

- A functional diagram showing the internal components of a 555 timer is shown in Figure 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 k Ω** resistors provides a trigger level of **1/3 VCC** and a threshold level of **2/3 VCC**.

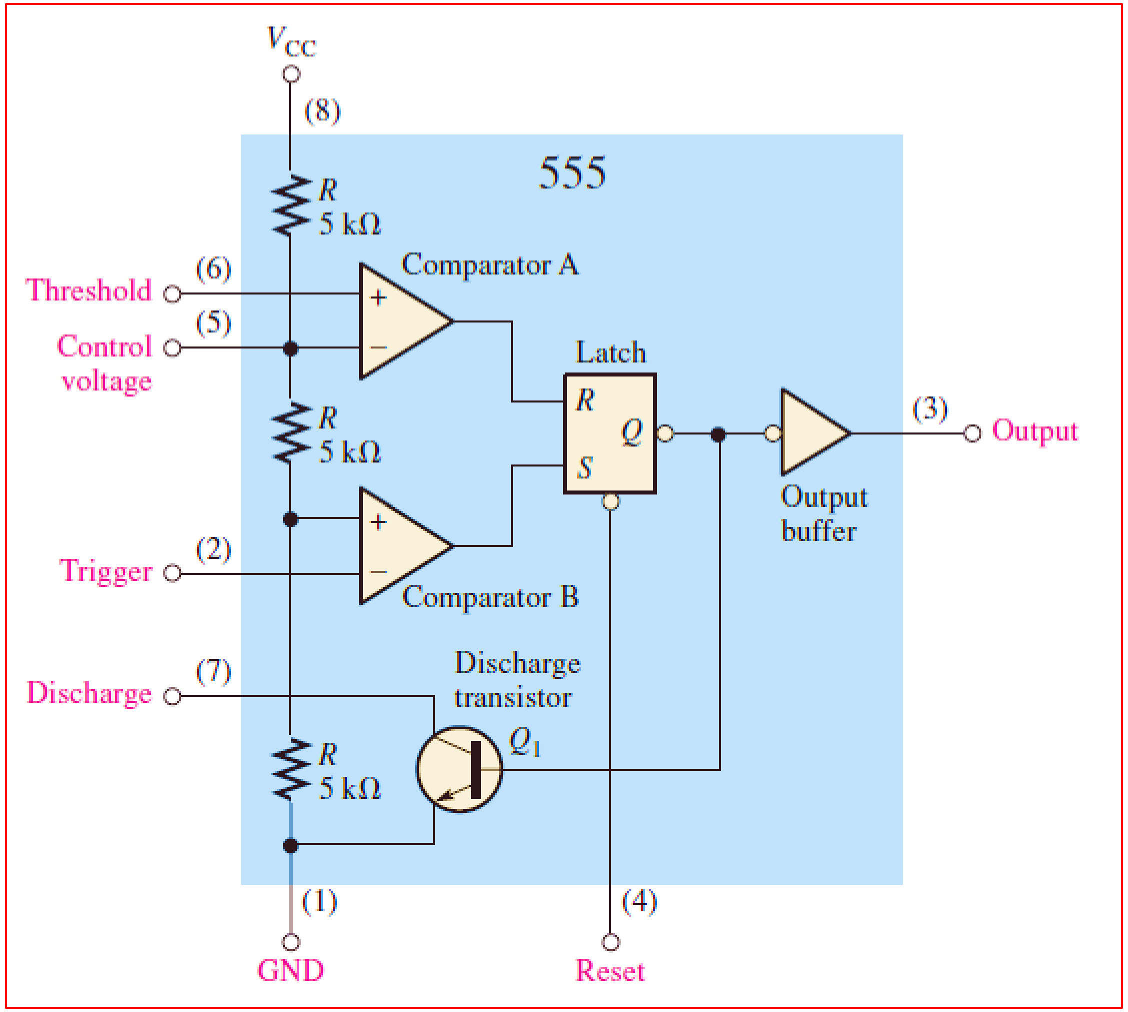


FIGURE 52 Internal functional diagram of a 555 timer (pin numbers are in parentheses).

- 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.

Monostable (One-Shot) Operation

- An external resistor and capacitor connected as shown in Figure 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:

$$t_w = 1.1\, R_1 C_1 \qquad \text{Eq. 3}$$

- 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.

- 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 54(a).

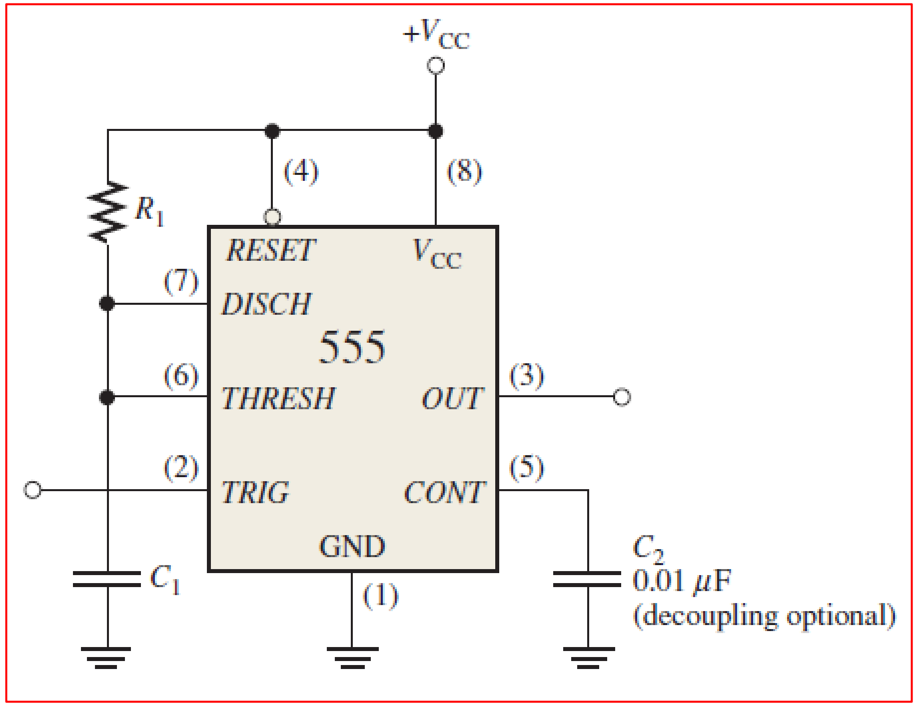
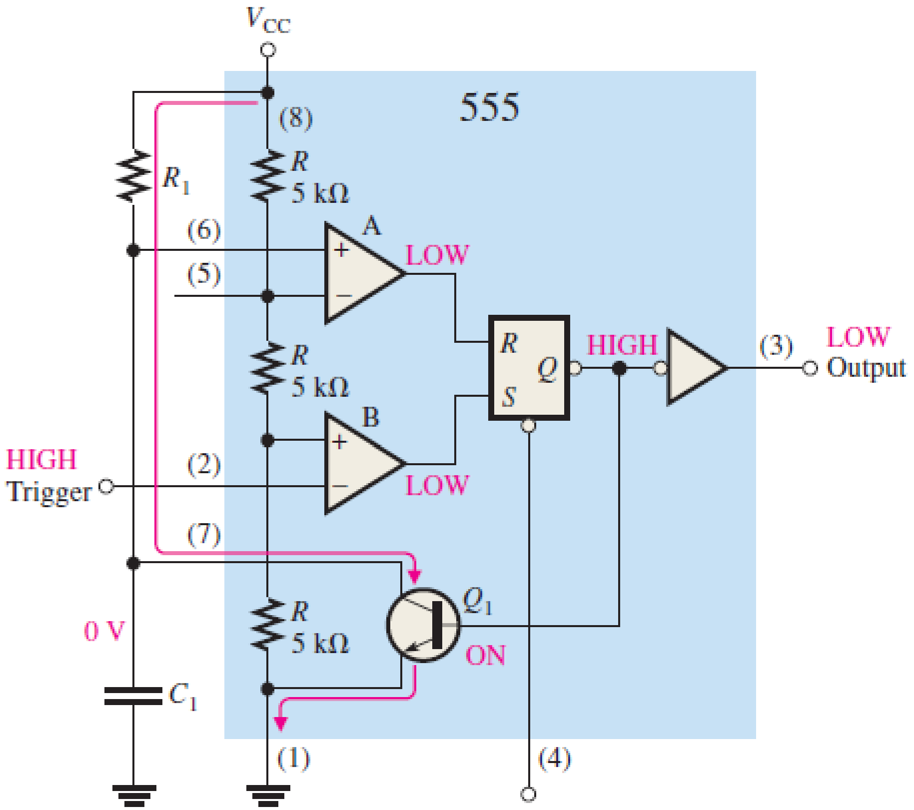


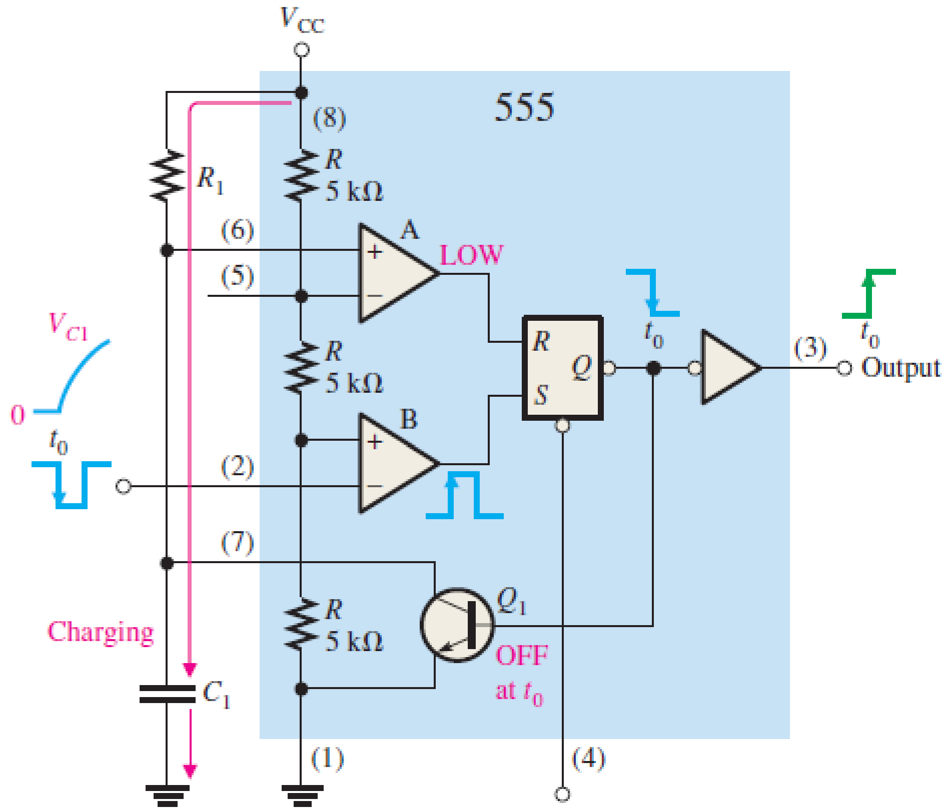
FIGURE 53 The 555 timer connected as a one-shot.

- 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**.



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



(b) When triggered

Example 13

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

Solution

From Equation 3 the pulse width is

$$t_W = 1.1\, R_1 C_1 = 1.1\,(2.2\ k\Omega)\,(0.01\ \mu F) = 24.2\ \mu S$$

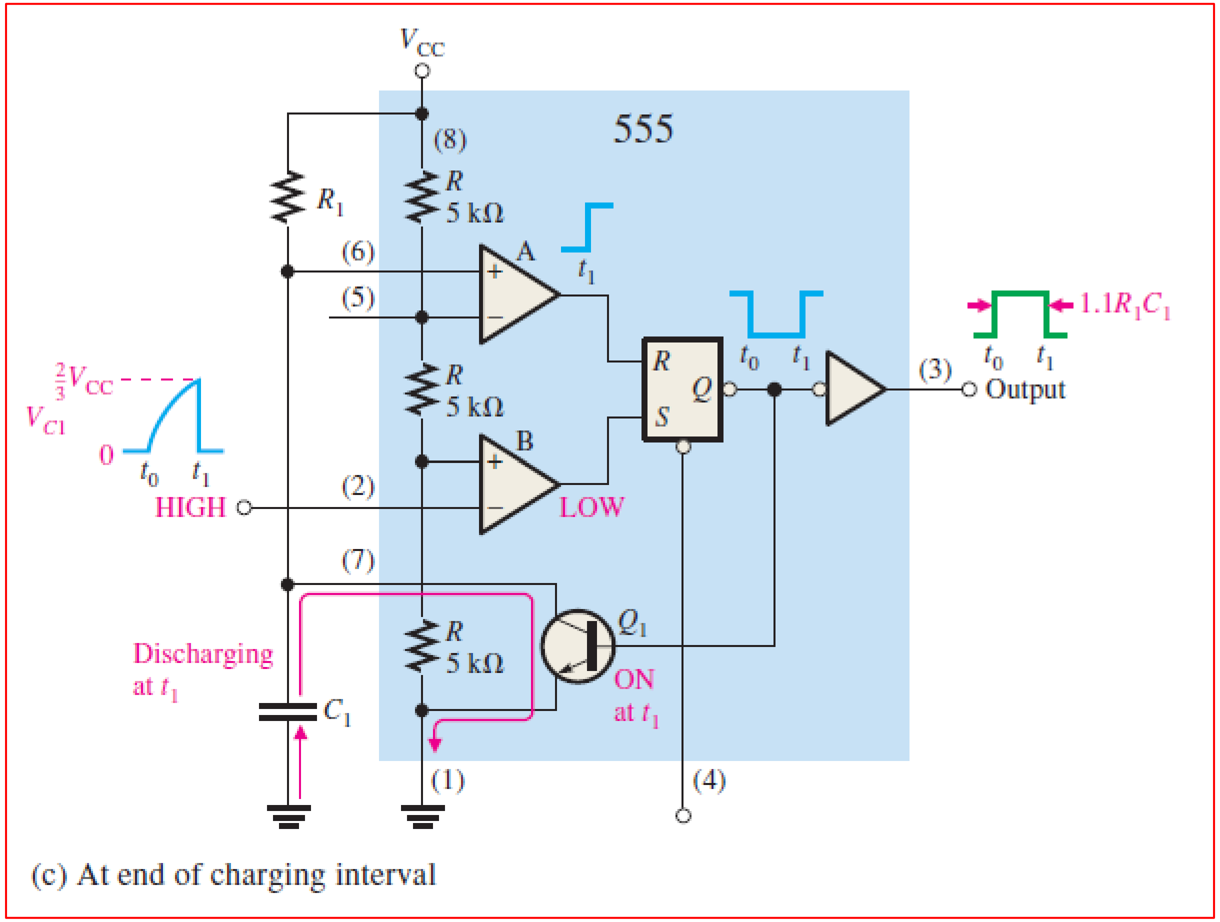


FIGURE 54 One-shot operation of the 555 timer.

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**.
- Figure 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 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.

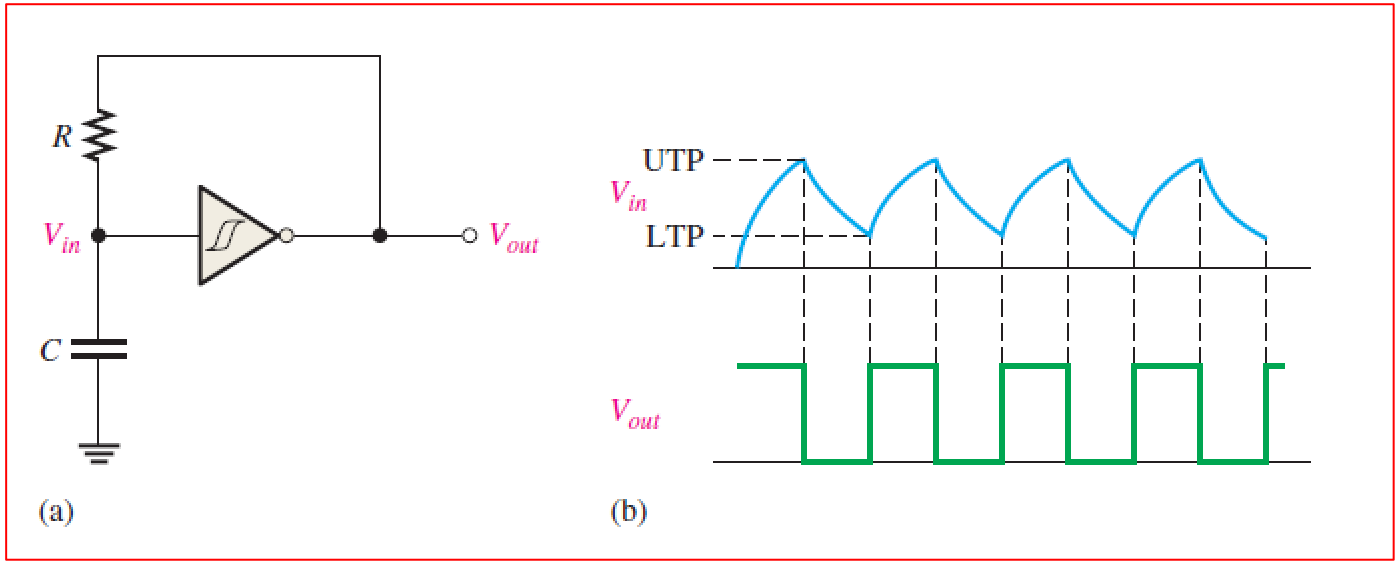


FIGURE 55 Basic astable multivibrator using a Schmitt trigger.

The 555 Timer as an Astable Multivibrator

- A 555 timer connected to operate as an astable multivibrator is shown in Figure 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 µF 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.

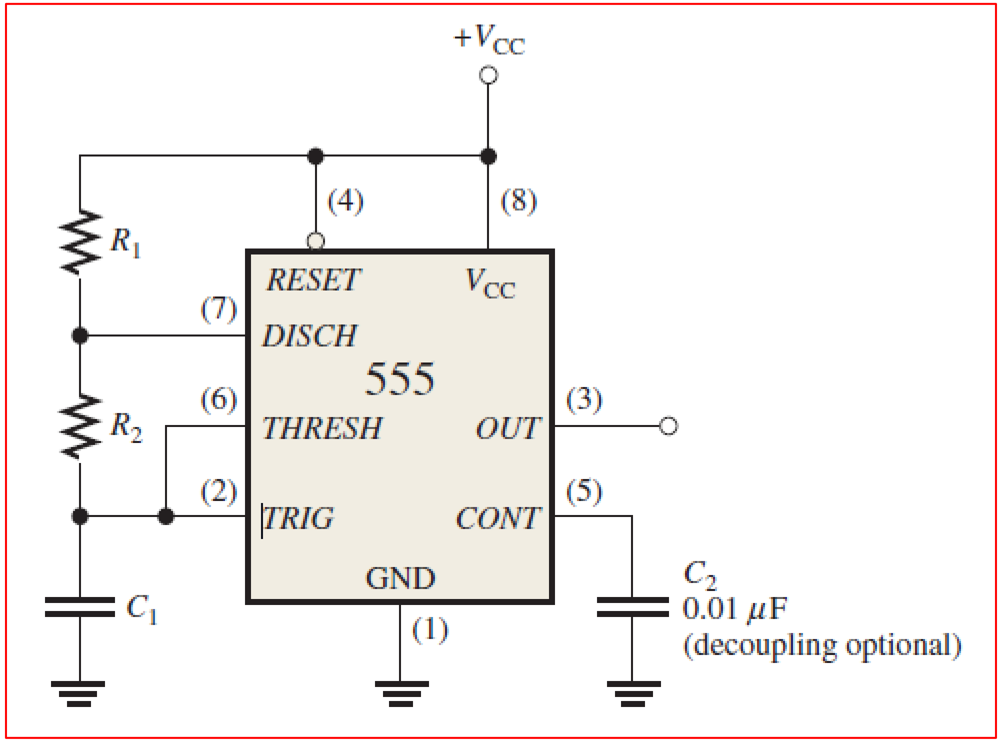


FIGURE 56 The 555 timer connected as an astable multivibrator (oscillator).

- 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 57.
- When the capacitor voltage reaches1/3 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 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 58.

$$\boldsymbol{f} = \frac{\mathbf{1.44}}{(\boldsymbol{R_1}+\mathbf{2}\boldsymbol{R_2})\boldsymbol{C_1}} \quad \text{......................Eq. 4}$$

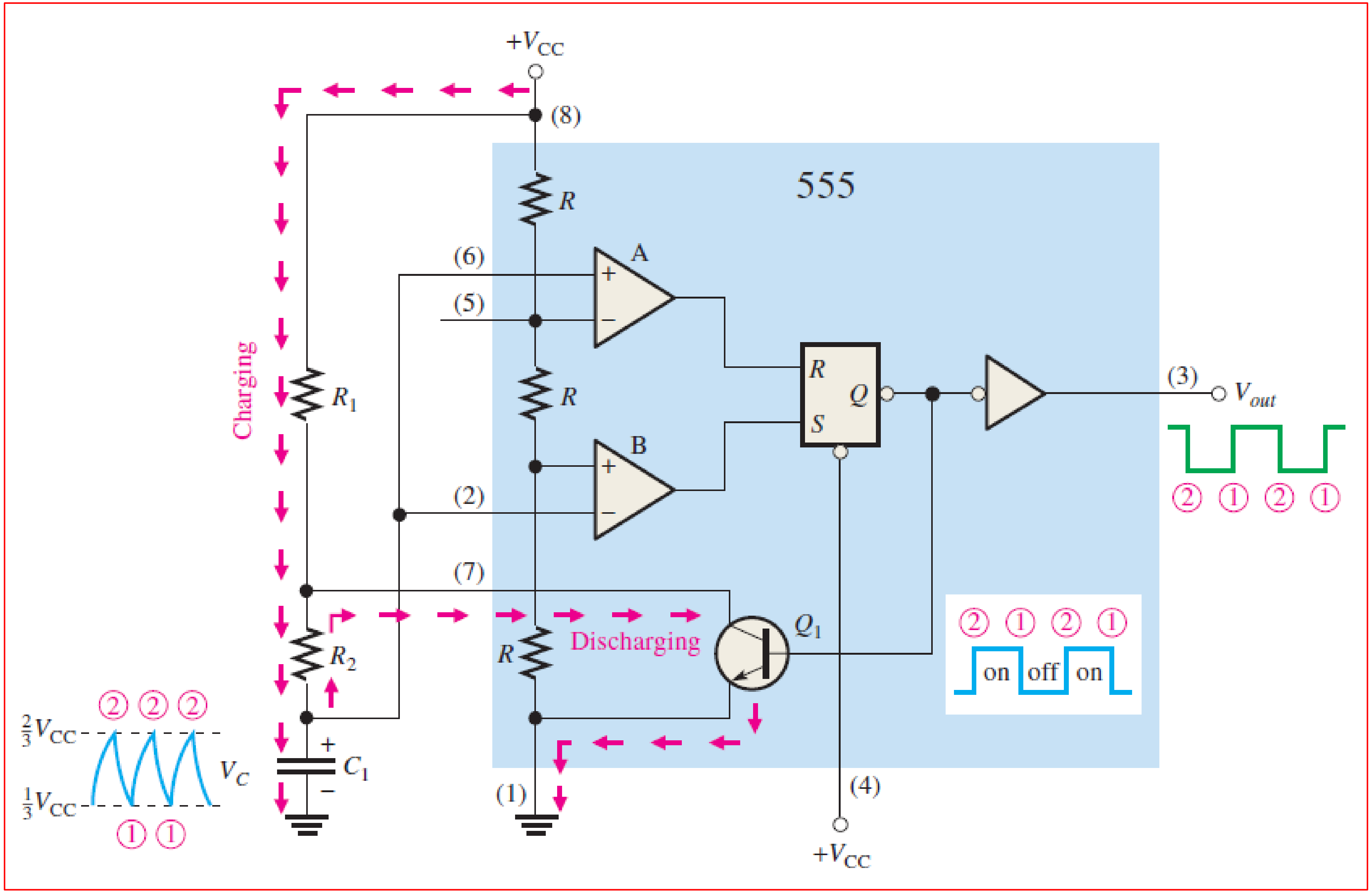


FIGURE 57 Operation of the 555 timer in the astable mode.

- 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 $R_2 >> R_1$ 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

$$t_H = 0.7(R_1 + R_2)C_1 \ldots\ldots\ldots\ldots\ldots\ldots Eq.5$$

- 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

$$t_L = 0.7(R_2)C_1 \ldots\ldots\ldots\ldots\ldots\ldots Eq.6$$

- The period, T, of the output waveform is the sum of t_H and t_L. This is the reciprocal of f_{in} Equation 4.

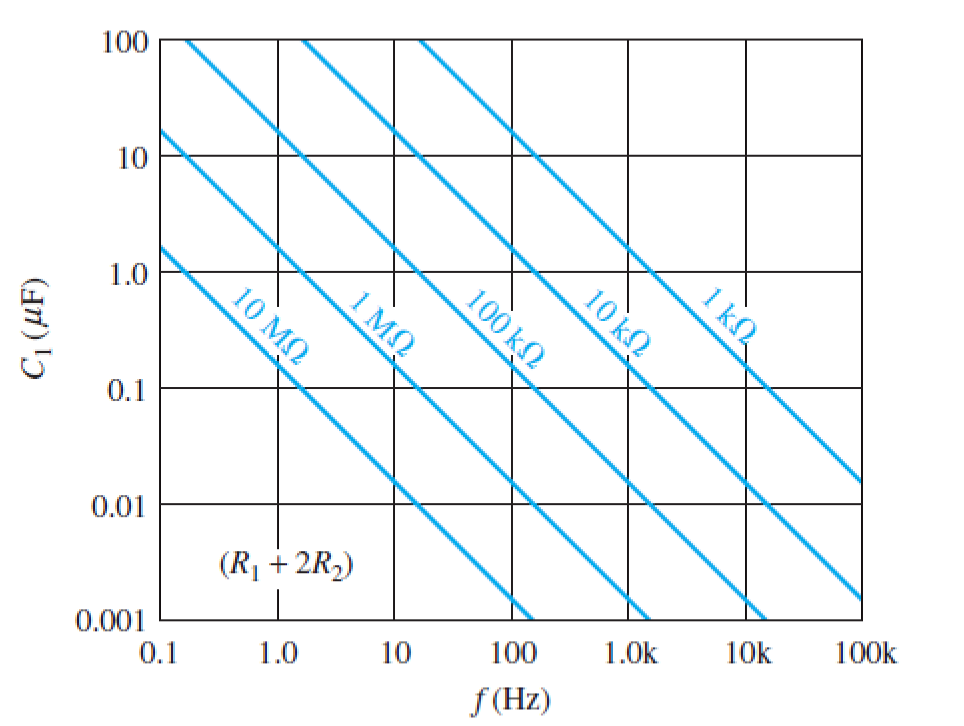


FIGURE 58 Frequency of oscillation as a function of C_1 and $R_1 + 2R_2$. The sloped lines are values of $R_1 + 2R_2$.

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

Finally, the duty cycle is

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

$$\text{Duty Cycle} = \left(\frac{R_1+R_2}{R_1+2R_2}\right)100\% \ldots\ldots\ldots\ldots\ldots Eq.7$$

To achieve duty cycles of less than 50 percent, the circuit in Figure 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 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

$$\text{Duty Cycle} = \left(\frac{R_1}{R_1+R_2}\right)100\% \ldots\ldots\ldots\ldots\ldots Eq.8$$

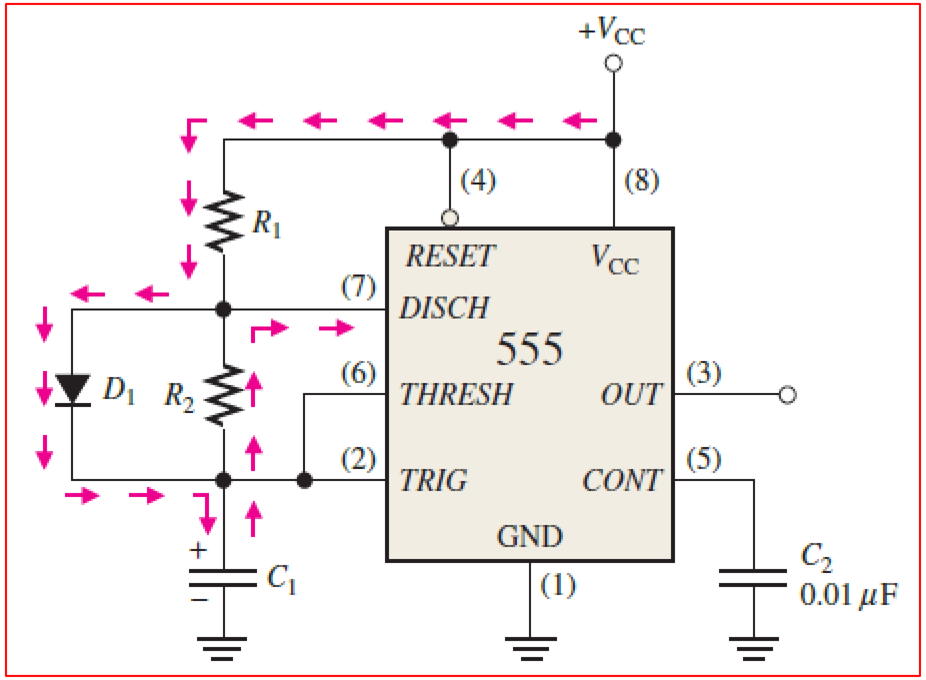


FIGURE 59 The addition of diode D_1 allows the duty cycle of the output to be adjusted to less than 50 percent by making R_1, R_2

EXAMPLE 14

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

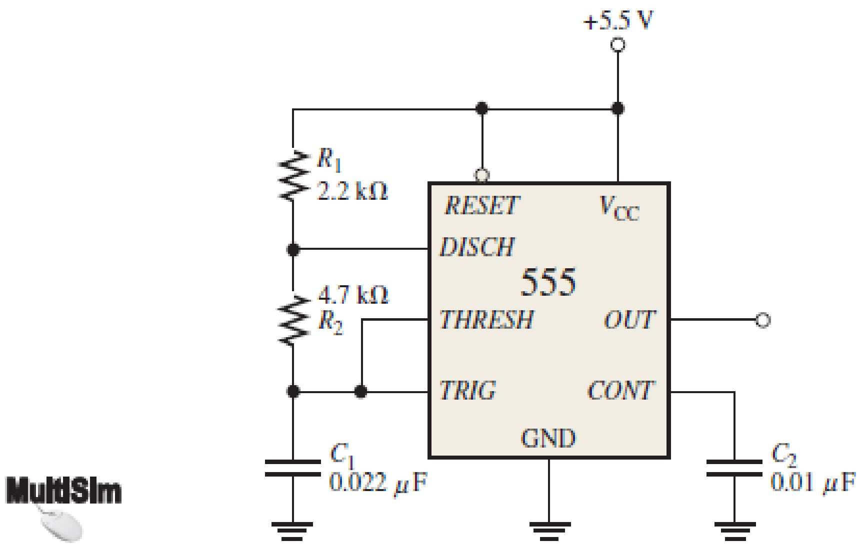


FIGURE 60

Solution

Use Equations 7–4 and 7–7.

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

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