TIMER CIRCUITS

The 555 Timer

The 555 timer is a versatile and widely used device because it can be configured in two different modes either as a ***monostable multivibrator (one-shot)*** or as an ***astable multivibrator (oscillator)***. An astable multivibrator has no stable states and therefore changes back and forth (oscillates) between two unstable states without any external triggering.

Basic Operation

A functional diagram showing the internal components of a 555 timer is given in Fig. (1).

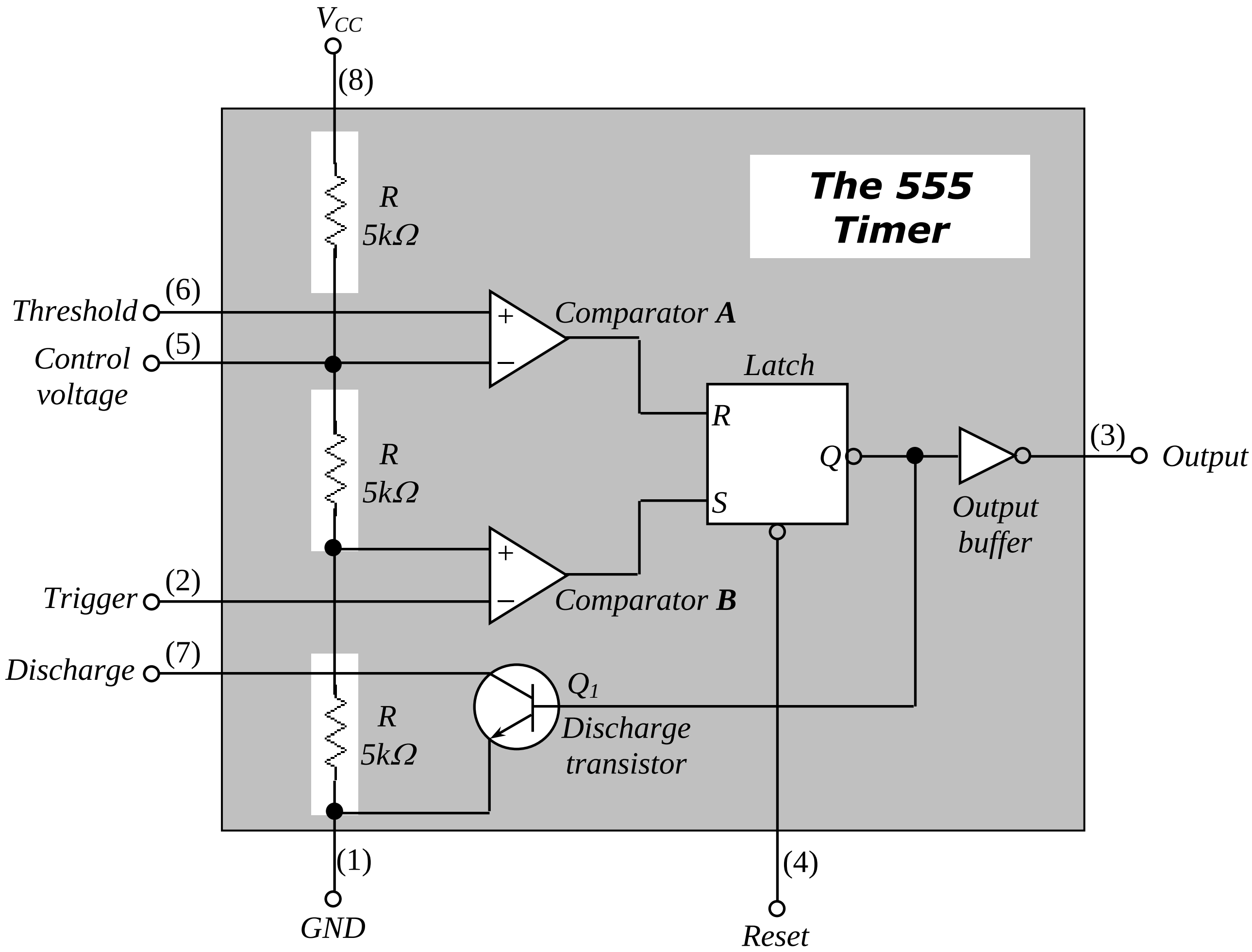


Fig. (1): Internal functional diagram of a 555 timer (Pin numbers are in parentheses).

The comparators are device 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 $1/3V_{CC}$ and a threshold level of $2/3V_{CC}$. 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 $1/3V_{CC}$, the output of comparator **B** switches from **LOW** to **HIGH** and set 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 $2/3V_{CC}$ 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 input (*pin 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 Fig. (2) are used to set up the 555 timer as a non-retriggerable one-shot. The pulse width of the output is determined by the timer constant of R_1 and C_1 according to the following formula:

$$t_W = 1.1\ R_1.C_1. \qquad (1)$$

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 discharge as shown in Fig. (3a). When a negative-going trigger pulse is applied, the output goes **HIGH** and the discharge transistor turns off, allowing capacitor C_1 to begin charging through R_1 as shown in Fig. (3b). When C_1 charges to $1/3V_{CC}$, the output goes back **LOW** and Q_1 turn on immediately, discharging C_1 as shown in Fig. (3c). As you can see, the charging rate of C_1 determines how long the output is **HIGH**.

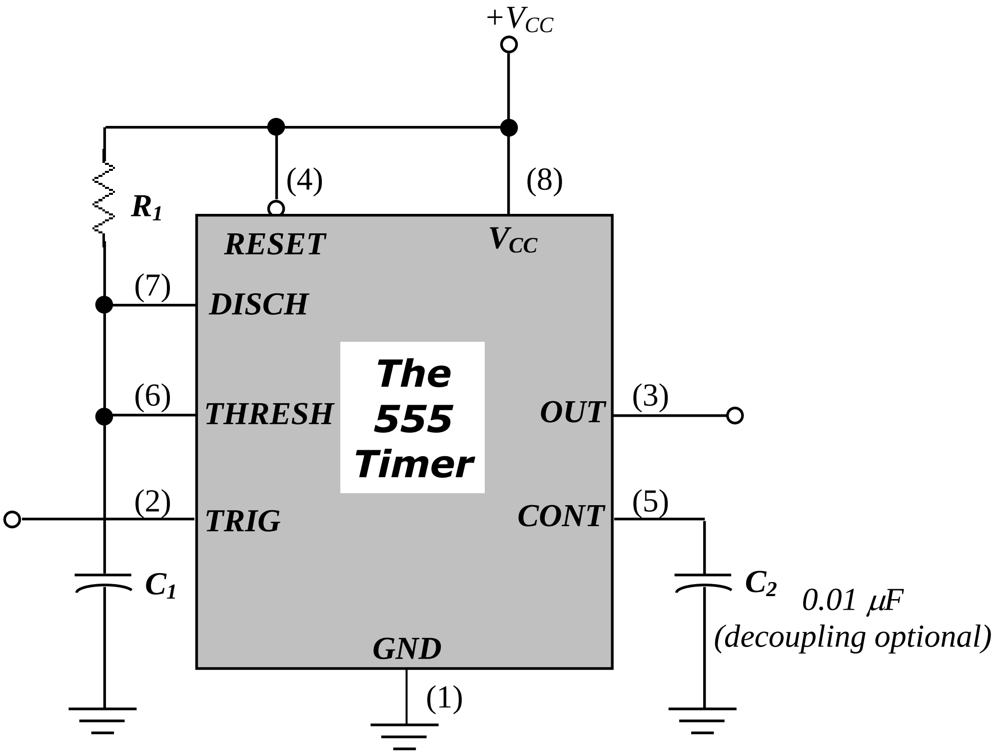


Fig. (2): The 555 timer connected as a one-shot.

EXAMPLE.1

What is the output pulse width for a 555 monostable circuit with R_1**=2.2 kΩ** and **C1=0.01 μF**?

Solution

From equation (1) the pulse width is

$t_w=1.1\ R_1.C_1=1.1*(2.2\ k\Omega)*(0.01\ \mu F)=24.2\ \mu s$.

Homework

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

Fig. (3a): Prior for triggering.

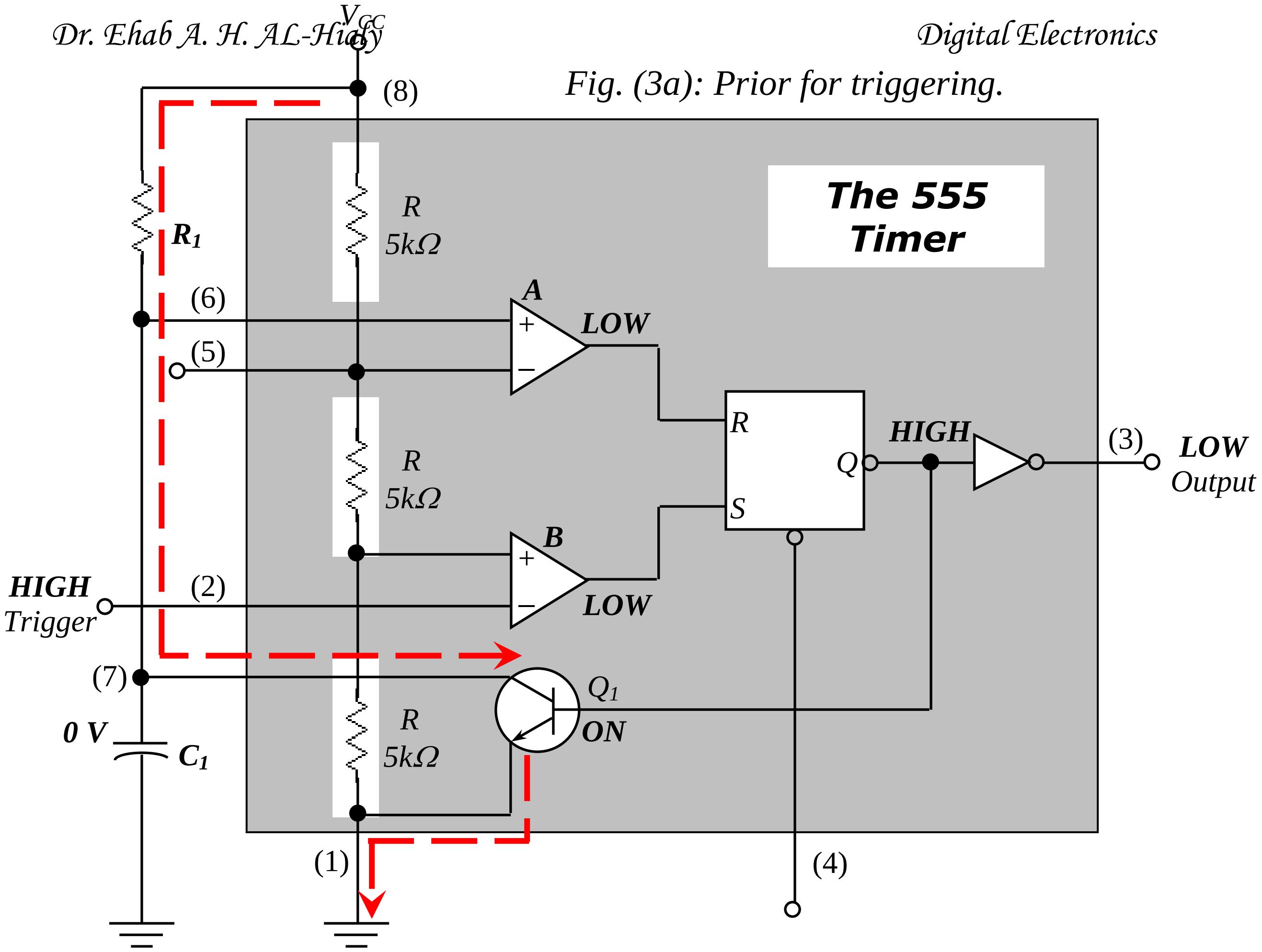
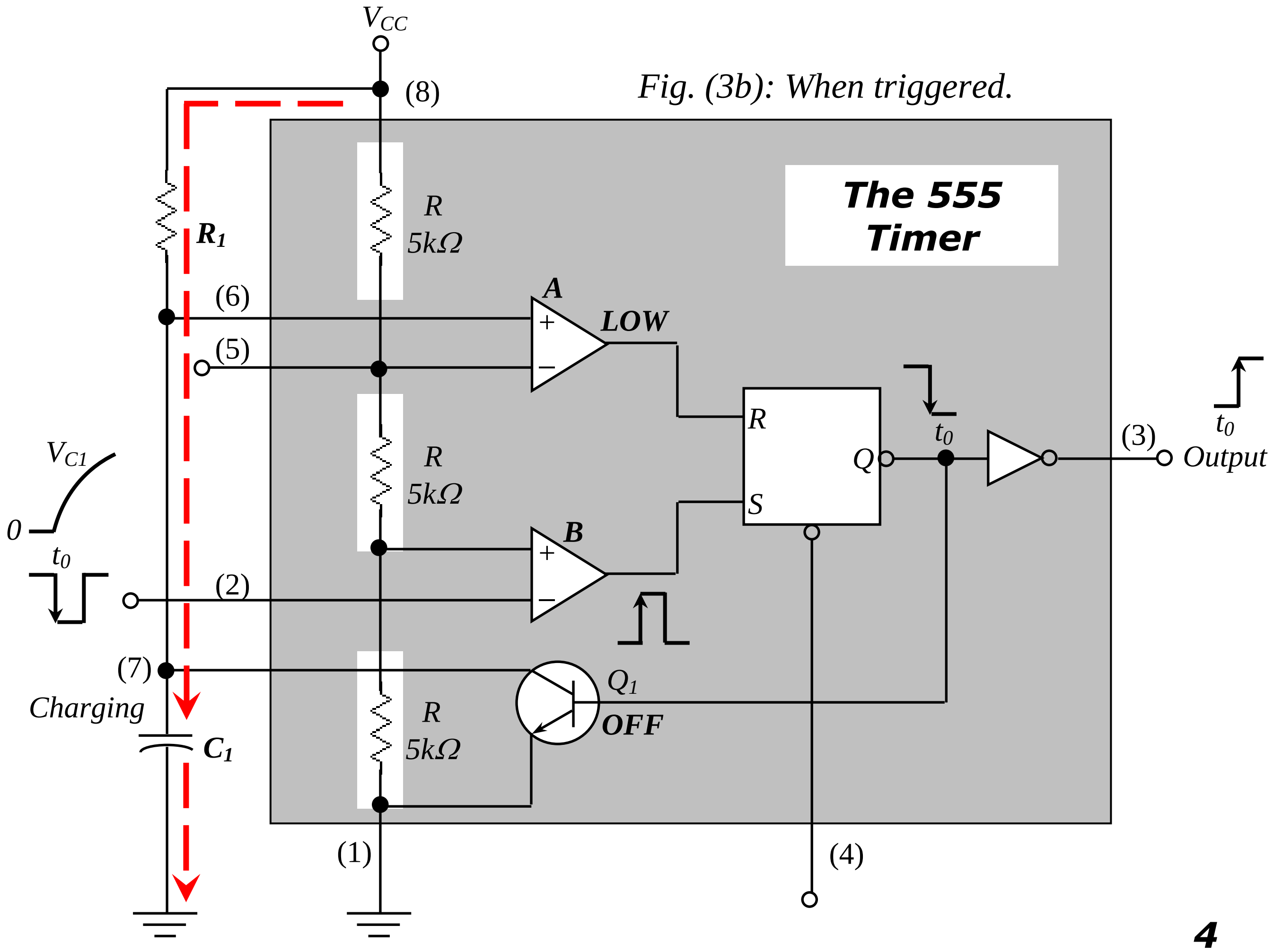


Fig. (3b): When triggered.



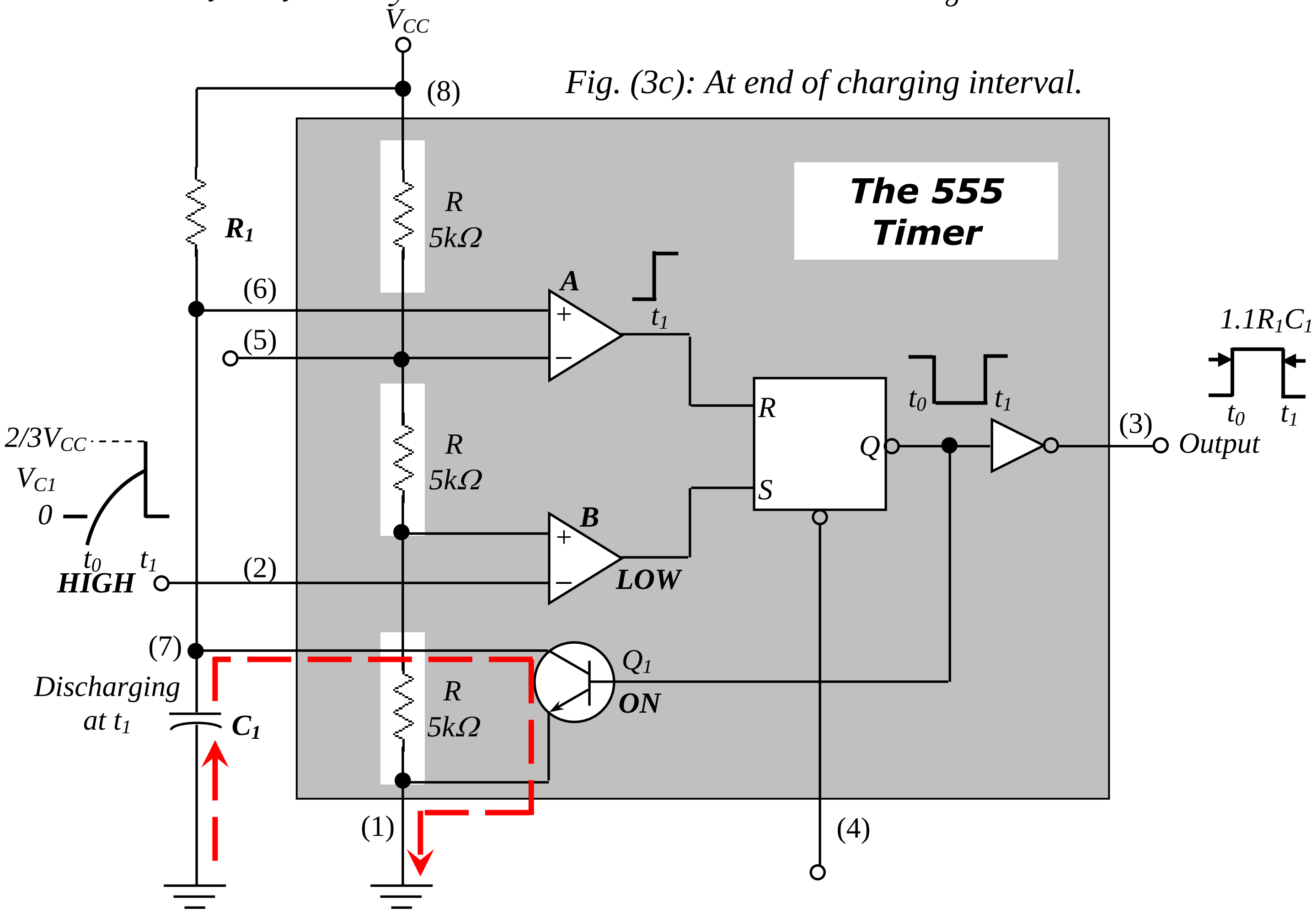


Fig. (3c): At end of charging interval.

Astable Operation

A 555 timer connected to operate as an ***astable*** multivibrator, which is a non-sinusoidal ***oscillator***, is shown in Fig. (4). Notice that the threshold input (*THRESH*) is now connected to the trigger input (*TRIG*). The external components R_1, R_2, and C_1 from 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.

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 $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ as indicated in Fig. (5). When the capacitor voltage reaches $1/3V_{CC}$, comparator **B** switches to its **LOW** output state, and when the capacitor voltage reaches $2/3V_{CC}$, comparator **A** switches to its **HIGH** output state. This resets the latch, causing the base of $\boldsymbol{Q_1}$ to go **HIGH** and turning on the transistor. This sequence creates a discharge path for the capacitor through $\boldsymbol{R_2}$ 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 $1/3V_{CC}$, comparator **B** switches **HIGH**; this sets latch, making the base of $\boldsymbol{Q_1}$ **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 $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$. The frequency of oscillation is given by the formula

$$f = \frac{1.44}{(R_1 + 2R_2)C_1}. \qquad (2)$$

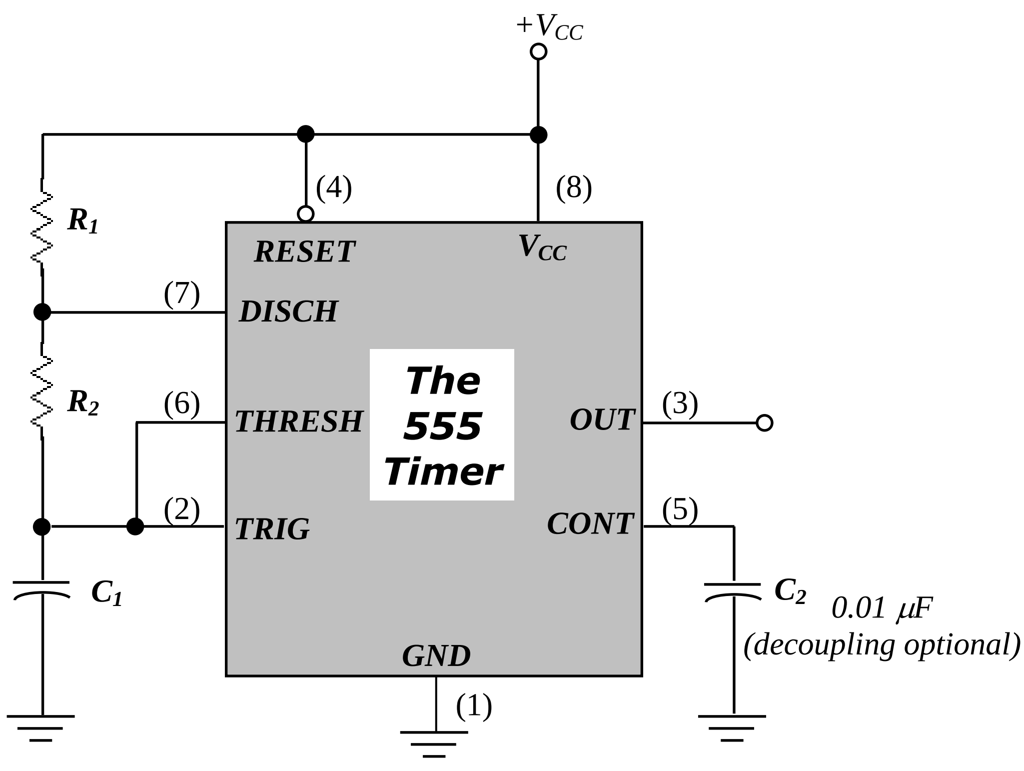


Fig. (4): The 555 timer connected as an astable multivibrator (oscillator).

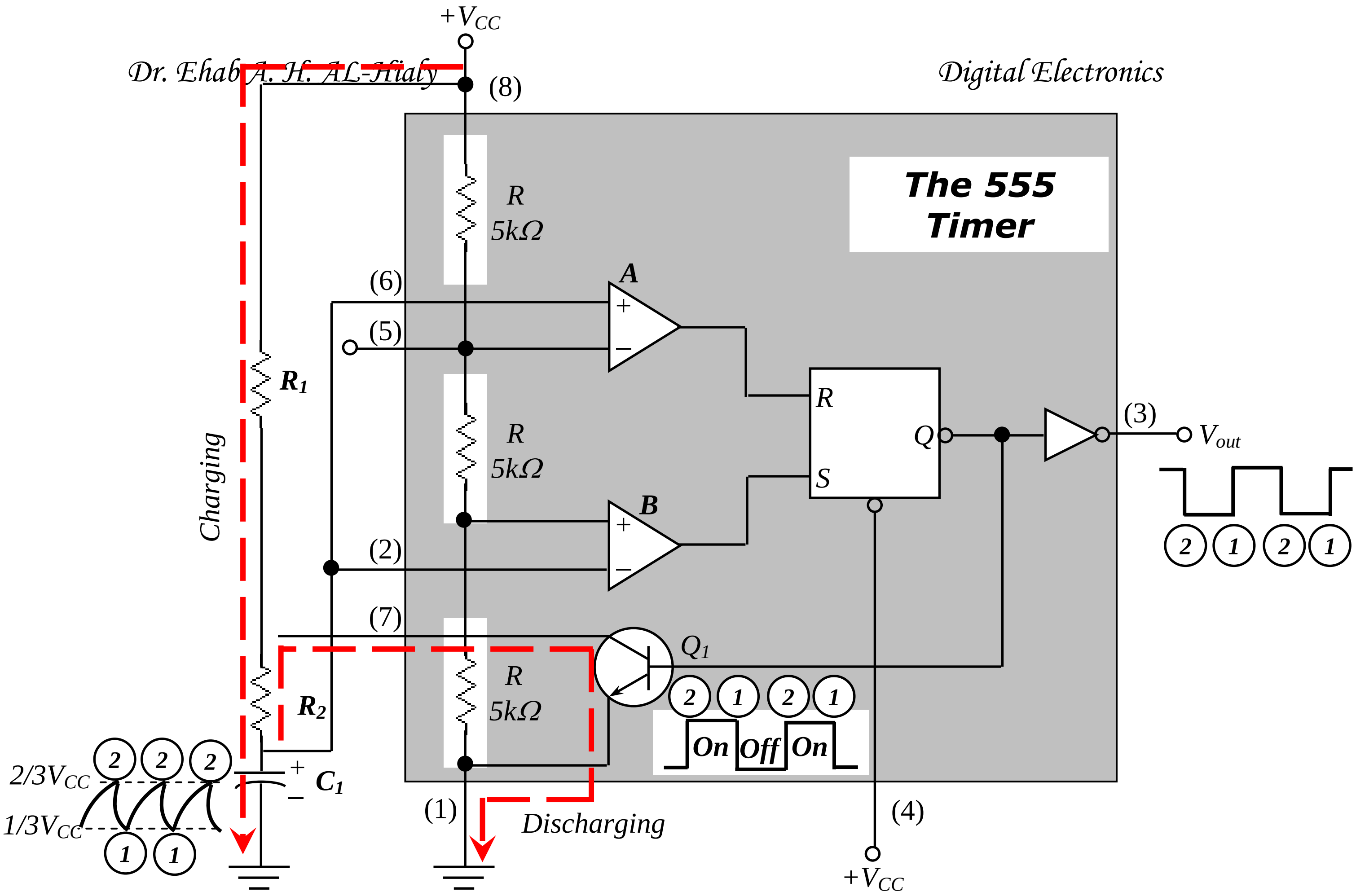


Fig. (5): Operation of 555 timer in the astable mode.

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 $1/3V_{CC}$ to $2/3V_{CC}$. It is expressed as

$$t_H = 0.7(R_1 + R_2)C_1. \qquad (3)$$

The time that the output is **LOW** (t_L) is how long it takes C_1 to discharge from $2/3V_{CC}$ to $1/3V_{CC}$. It is expressed as

$$t_L = 0.7R_2C_1. \qquad (4)$$

The period, T, of the output waveform is the sum of t_H and t_L.

$$T = t_H + t_L = 0.7(R_1 + 2R_2)C_1. \qquad (5)$$

This is the reciprocal of (*f*) in equation (2). Finally, the duty cycle is

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

$$Duty\ Cycle = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right) 100\%. \qquad (6)$$

To achieved duty cycles of less than 50 percent, the circuit in Fig. (4) can be modified so that $\boldsymbol{C_1}$ charges through only $\boldsymbol{R_1}$ and discharges through $\boldsymbol{R_2}$. This is achieved with a diode $\boldsymbol{D_1}$ placed as shown in Fig. (6). The duty cycle can be made less than 50 percent by making $\boldsymbol{R_1}$ less than $\boldsymbol{R_2}$. Under this expression for the duty cycle is

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

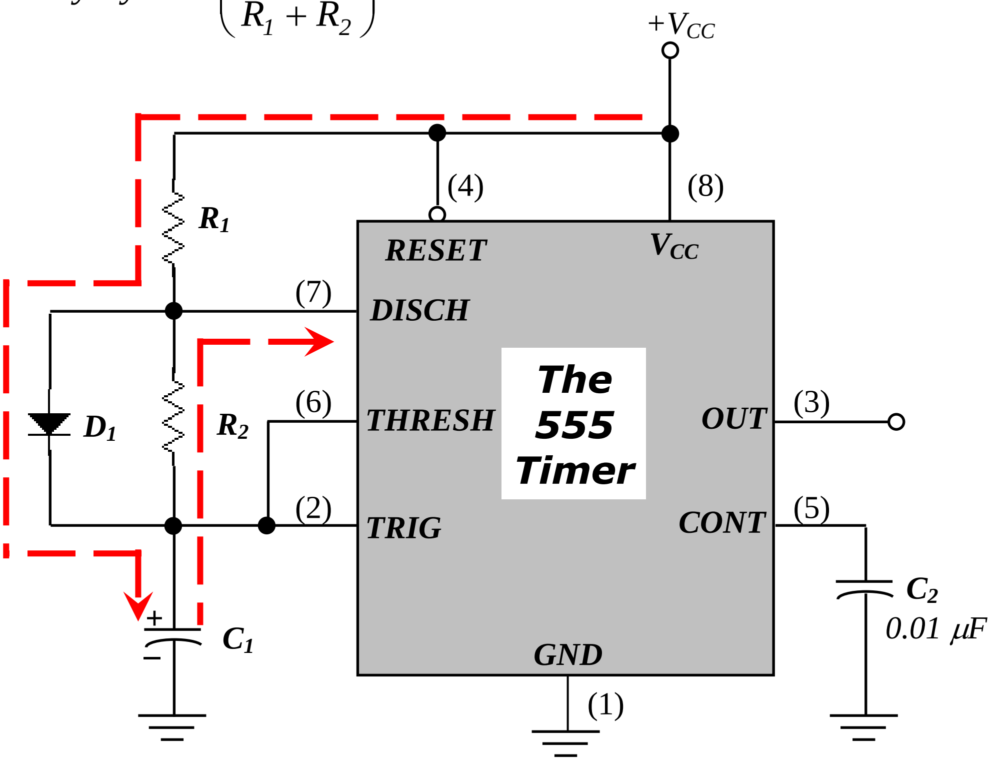
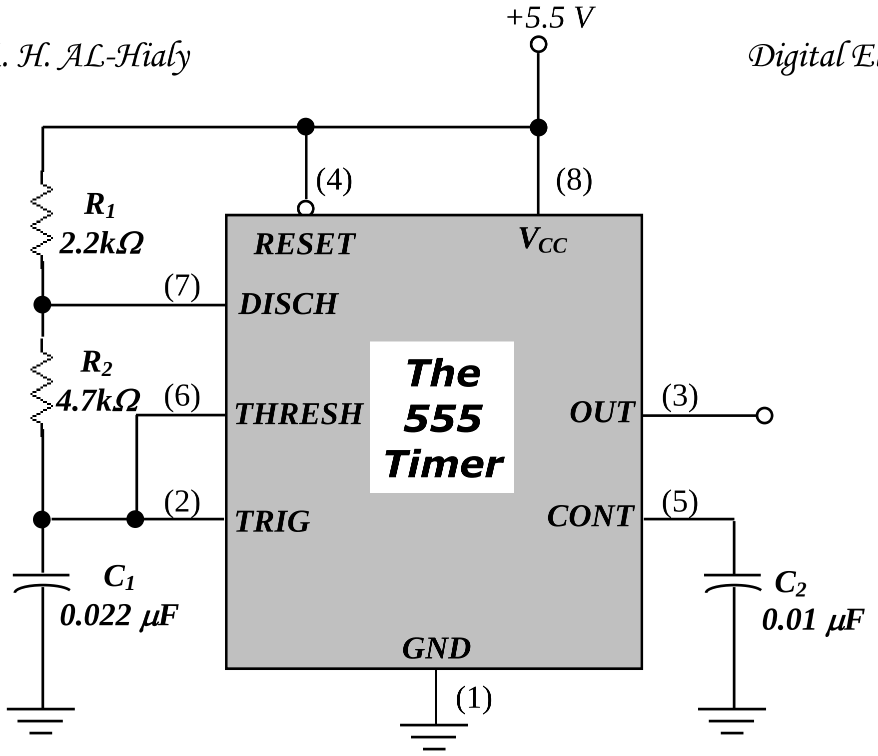


Fig. (6): The addition of diode D_1 allows the duty cycle of the output to be adjusted to less than 50 percent by making $R_1 < R_2$.

EXAMPLE.2

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



Solution

Use Equations (2 and 6).

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

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

Homework

Determine the duty cycle in figure above if a diode is connected across $\boldsymbol{R_2}$ as indicated in Fig. (6).