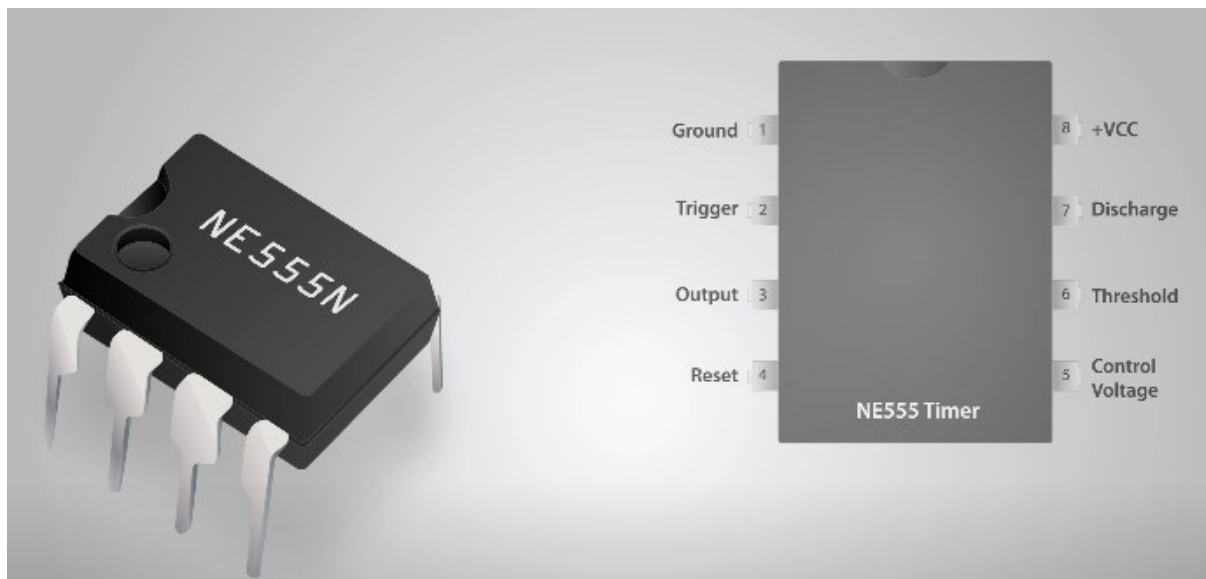


555 timer¹

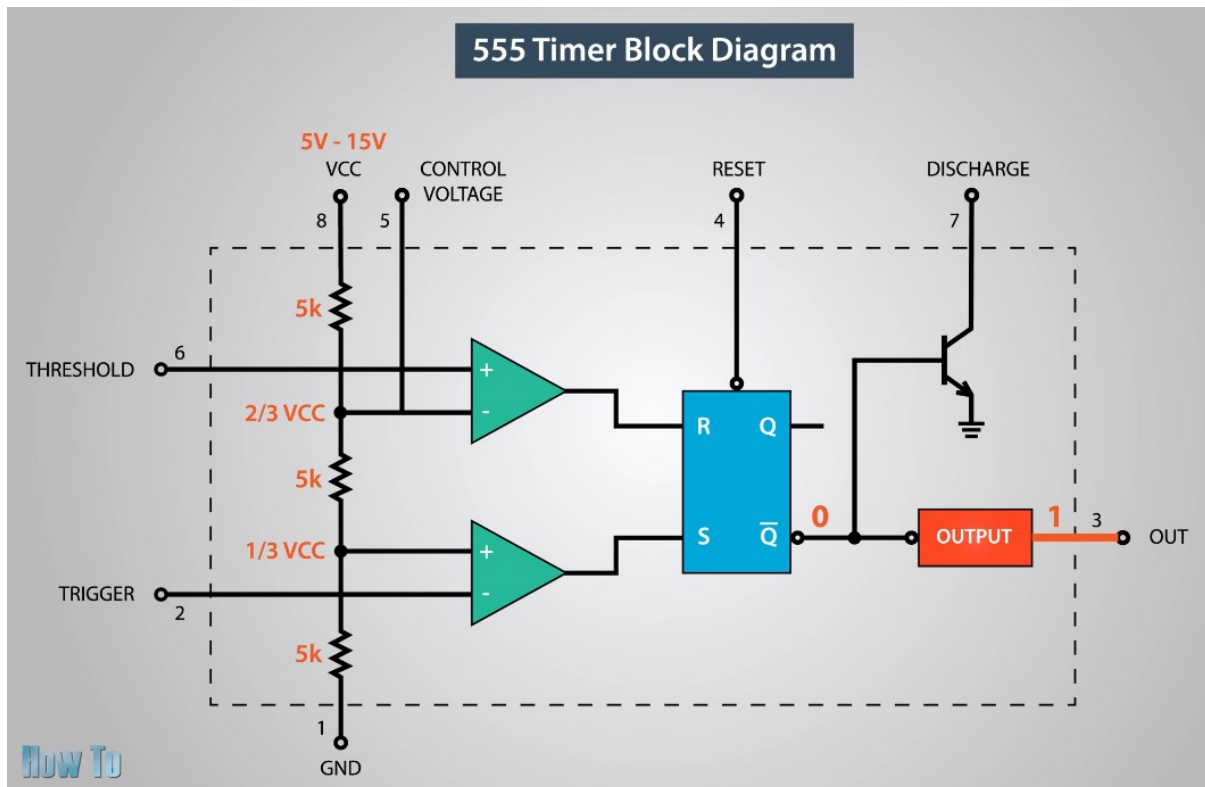
555 timer works, one of the most popular and widely used ICs of all time. The 555 timer designed by Hans Camenzind in 1971 can be found in many electronic devices starting from toys and kitchen appliances to even a spacecraft. It is a highly stable integrated circuit that can produce accurate time delays and oscillations.



The 555 timer has three operating modes: bistable, monostable and astable mode.

Let's take a closer look what's inside the 555 timer and explain how it works in each of these three modes. The internal schematic of the 555 timer consists of 25 transistors, 2 diodes and 15 resistors. Represented with a block diagram it consists of 2 comparators, a flip-flop, a voltage divider, a discharge transistor and output stage.

¹ Source : https://www.youtube.com/watch?v=iOSNb_dkYI



The *voltage divider* consists of three identical 5k resistors which create two reference voltages at $1/3$ and $2/3$ of the supplied voltage which can range from 5 to 15V.

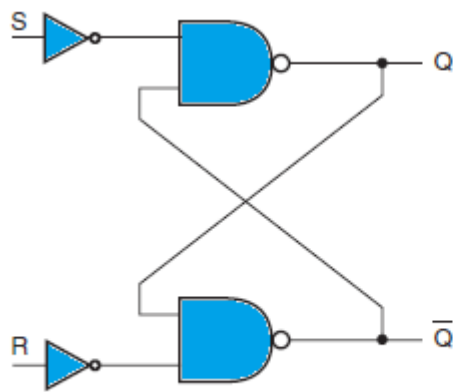
Next are the two comparators. A comparator is a circuit element that compares two analog input voltages at its positive non-inverting and negative inverting input terminal. If the input voltage at the positive terminal is higher than the input voltage at the negative terminal the comparator will output 1. Vice versa, if the voltage at the negative input terminal is higher than the voltage at the positive terminal the comparator will output 0.

The first comparator negative input terminal is connected to the $2/3$ reference voltage at the voltage divider and the external control pin, while the positive input terminal to the external threshold pin.

On the other hand the second comparator negative input terminal is connected to the trigger pin, while the positive input terminal to the $1/3$ reference voltage at the voltage divider.

So using these three pins Trigger, Threshold and Control we can control the output of the two comparators which are then fed to the R and S inputs of the flip-flop.

The **flip-flop** will output 1 when the R is 0 and S is 1 and vice versa, it will output 0 when R is 1 and S is 0. Additionally the flip-flop can be reset via the external pin called "Reset", which can override the two inputs, thus the reset the entire timer at any time.



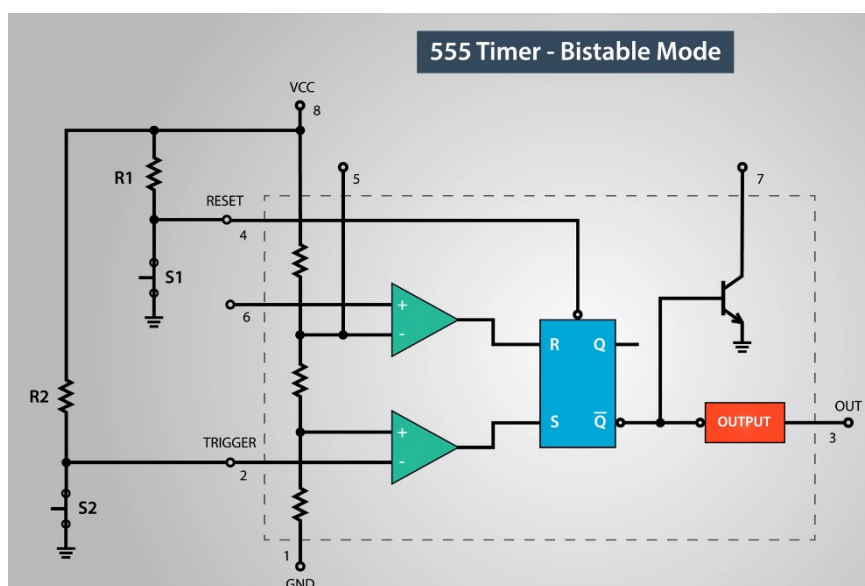
Operation Mode	S	R	Q_{n+1}
No change	0	0	Q_n
SET	1	0	1
RESET	0	1	0
Forbidden	1	1	—

R-S Flip-Flop

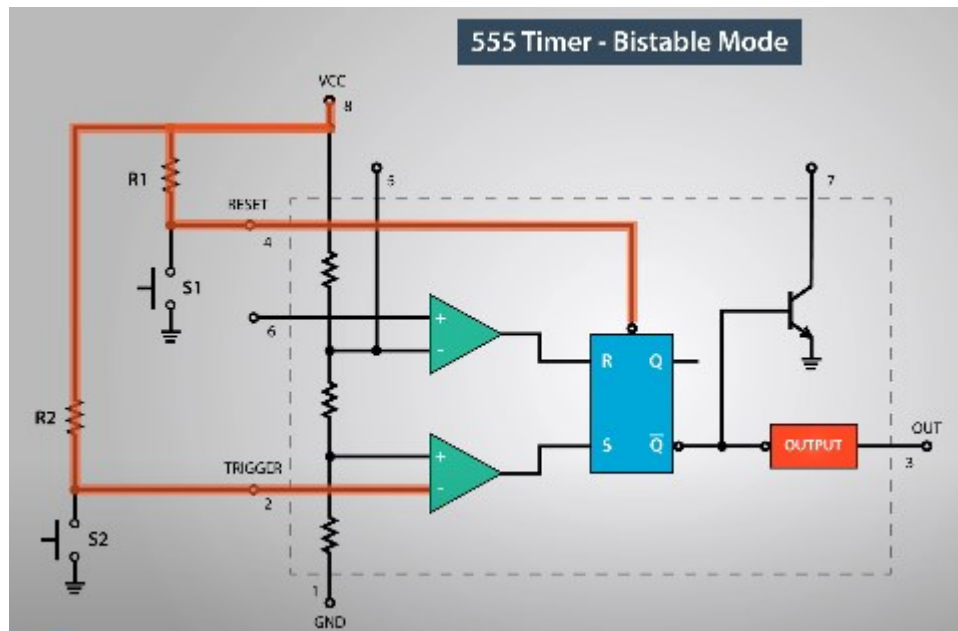
The Q-bar output of the flip-flop goes to the output stage or the output drivers which can either source or sink a current of 200 mA to the load. The output of the flip-flop is also connected to a transistor that connects the discharge pin to ground.

555 Timer: Bi-stable Mode

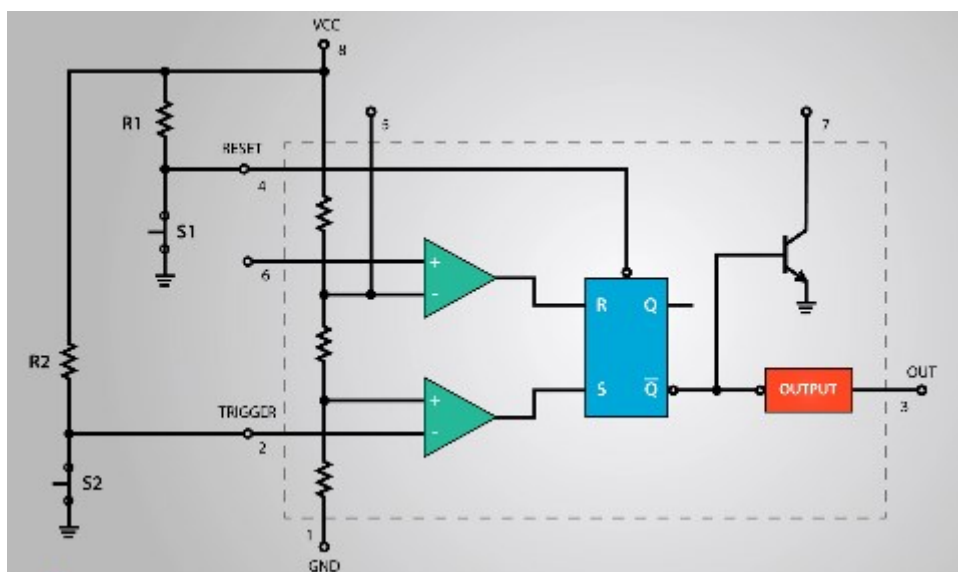
Now let's make an example of the 555 timer operating in a bi-stable mode.



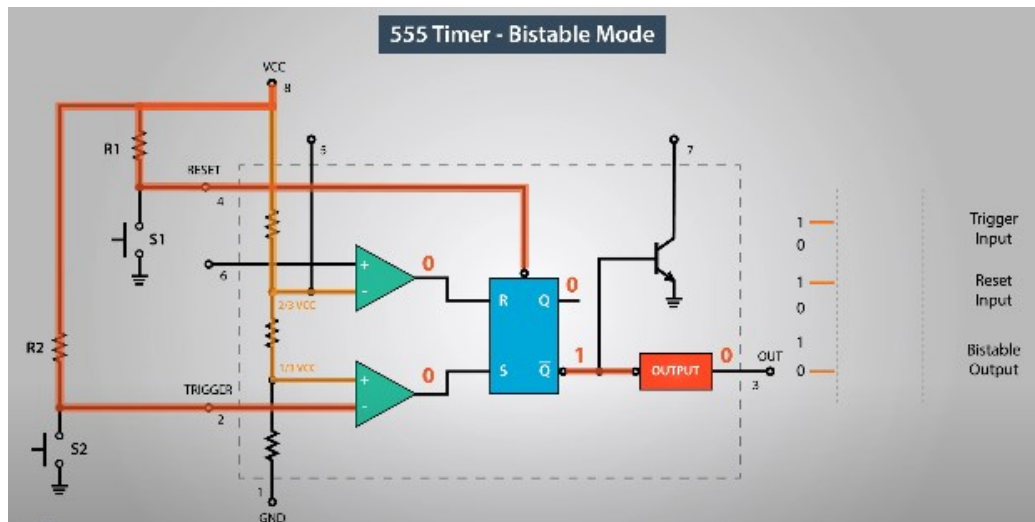
For that purpose we need two external resistors and two push buttons. The trigger and the reset pin of the IC are connected to VCC through the two resistors R1 and R2 and in that way they are always HIGH.



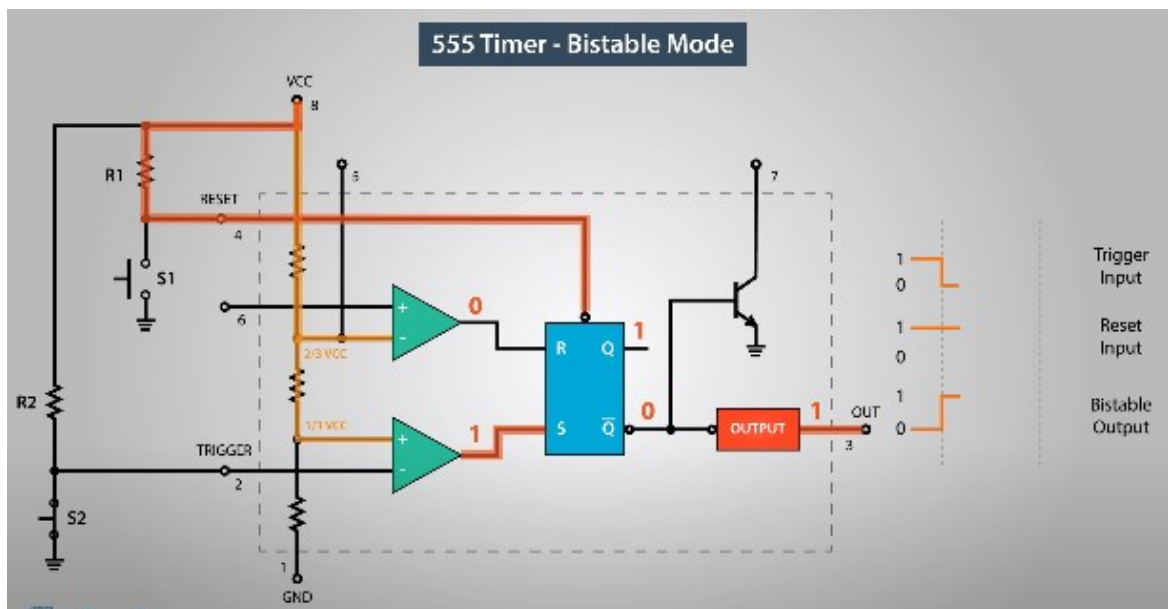
The two push buttons are connected between these pins and the Ground, so if we hold them push the input state will be LOW.



Initially the two comparators outputs are 0, thus the flip-flop output as well as the output of the 555 timer are 0.

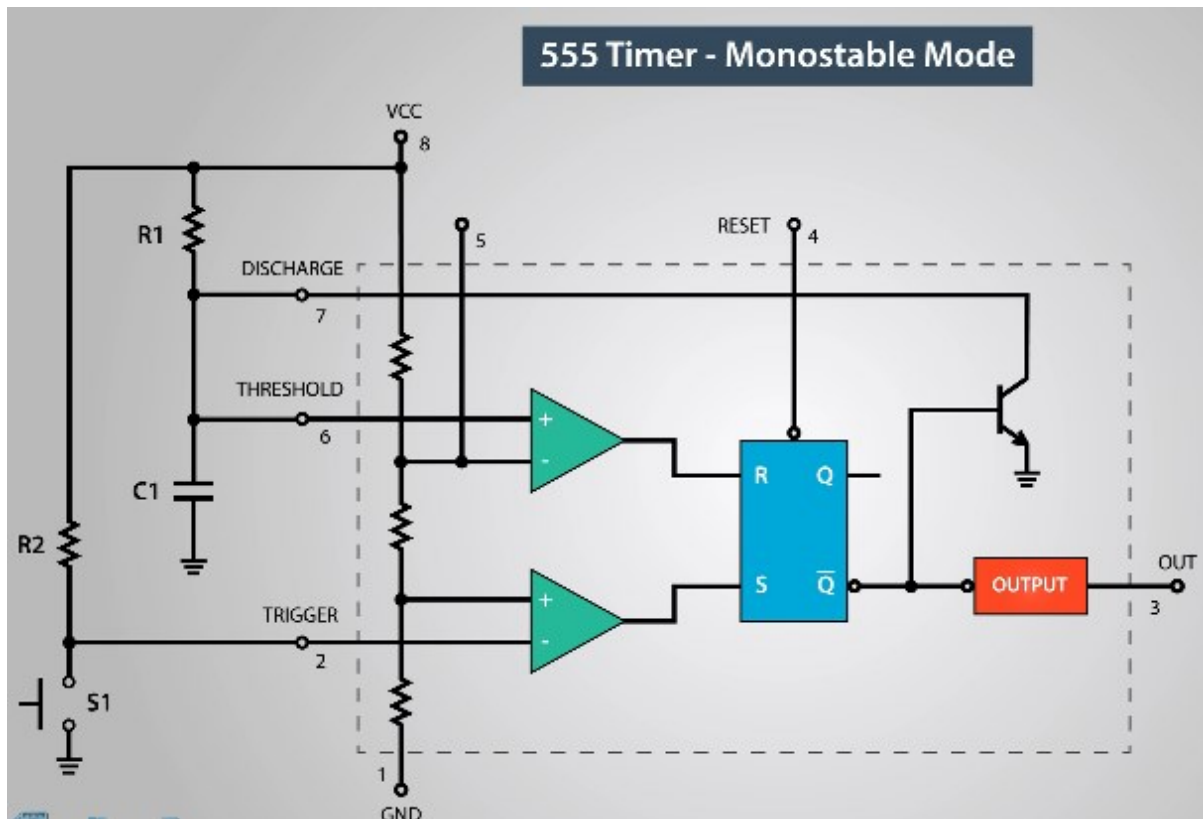


If we press the trigger push button the state that the trigger input will become LOW, so the comparator will output HIGH and it will make the flip-flop Q-bar output go LOW.

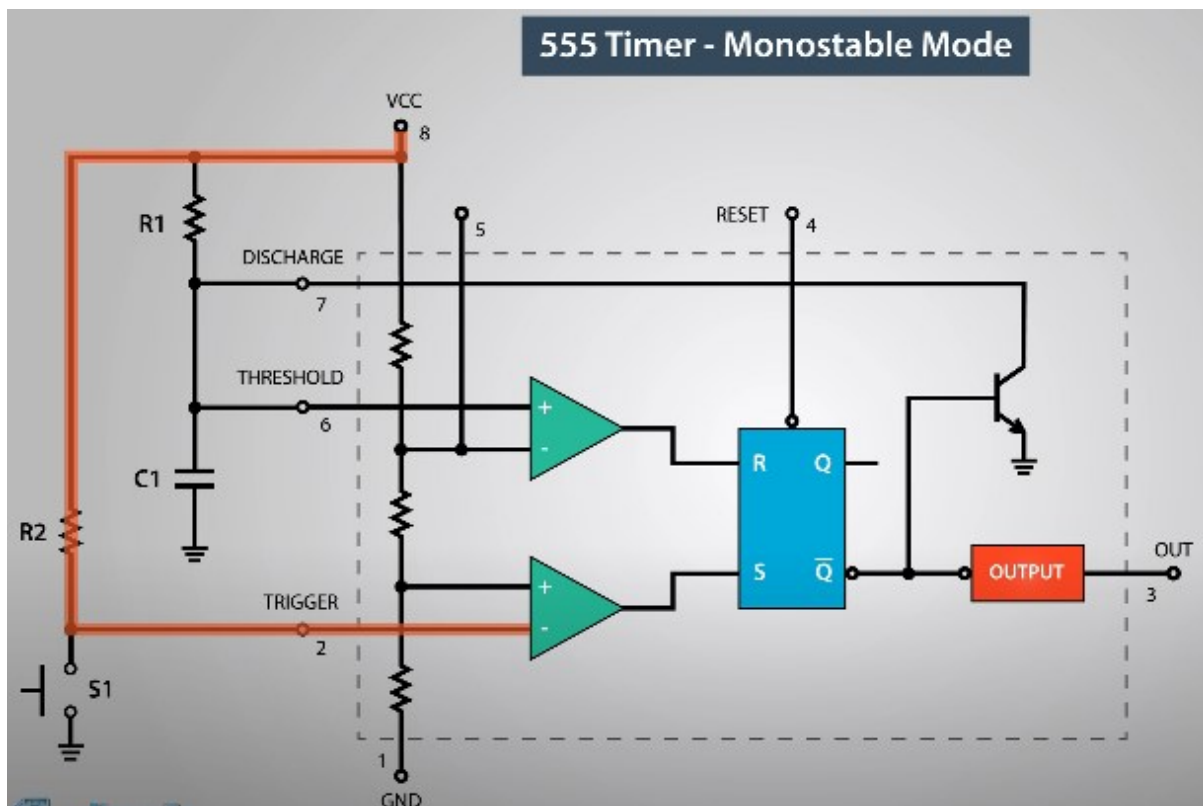


The output stage will invert this and the final output of the 555 timer will be HIGH.

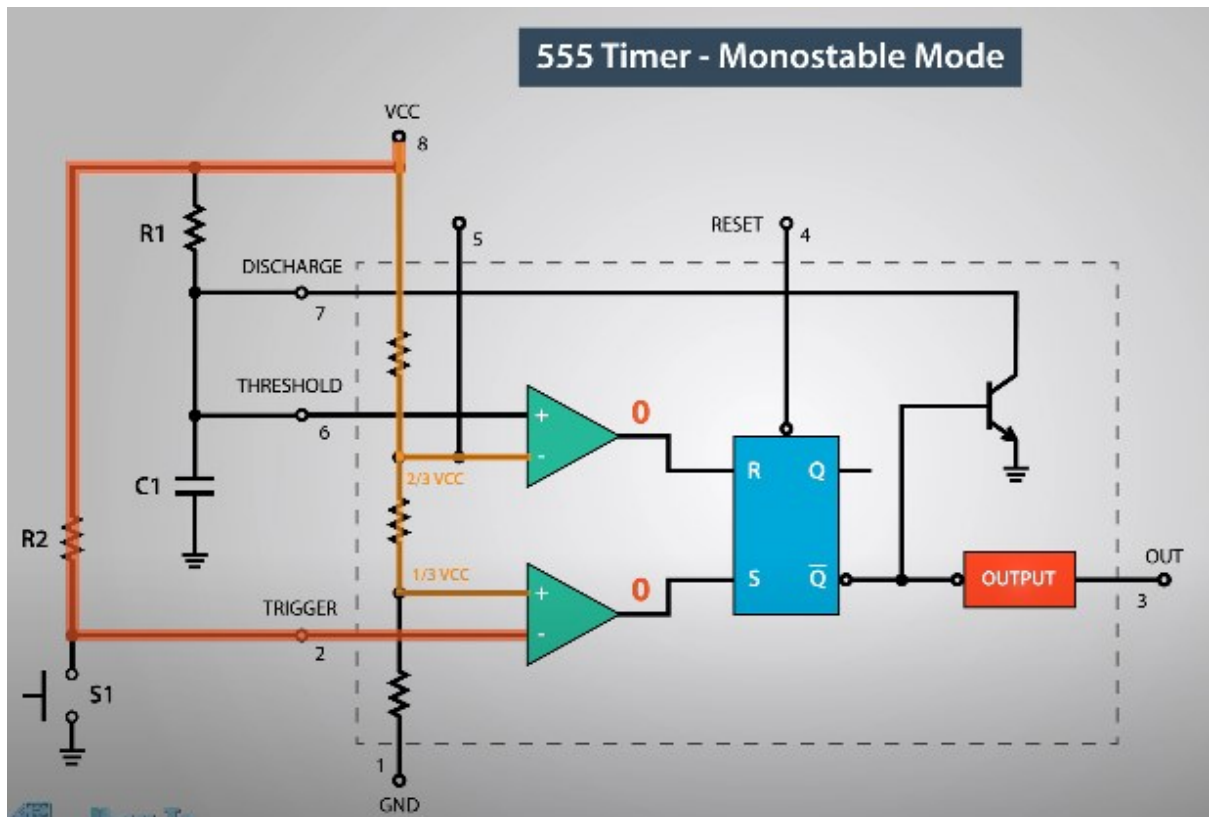
The output will remain HIGH even when the trigger push-button is not pushed because in that case the flip-flop inputs R and S will be zero which means that the flip-flop won't change its previous state.



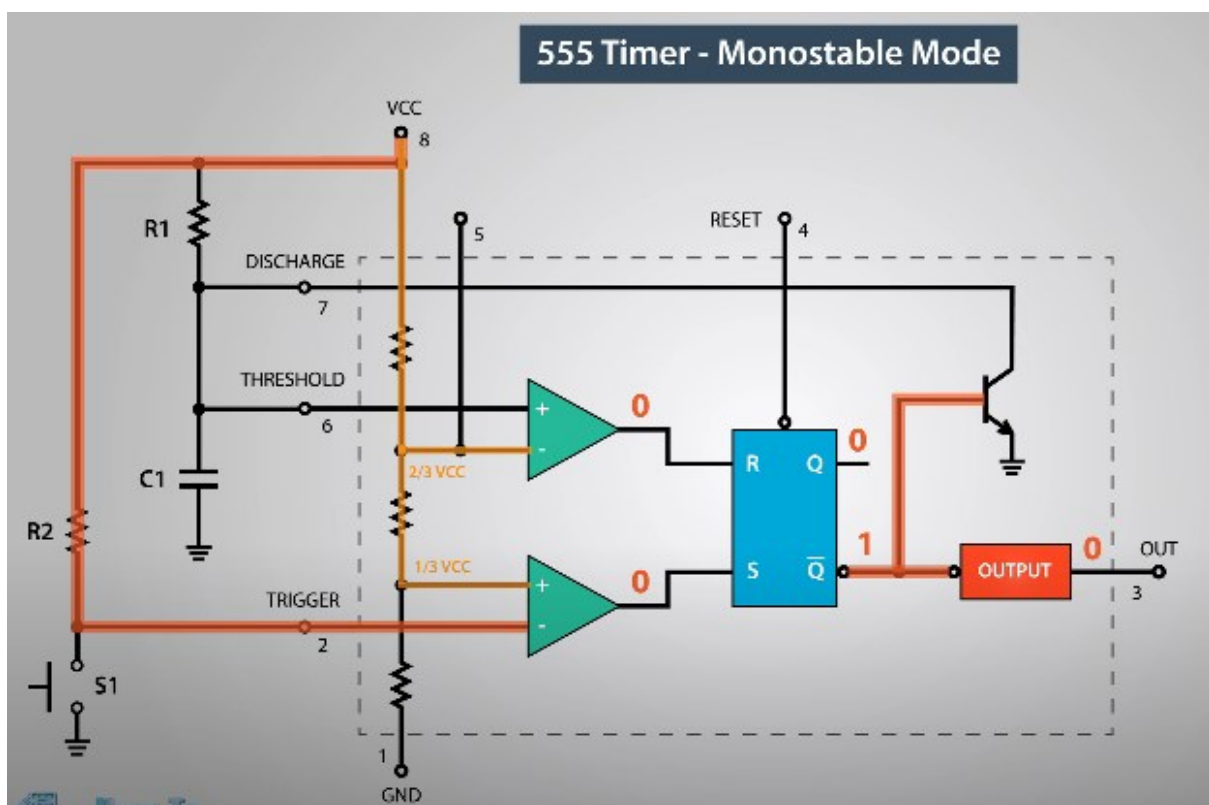
The trigger input is held HIGH by connecting it to VCC through a resistor.

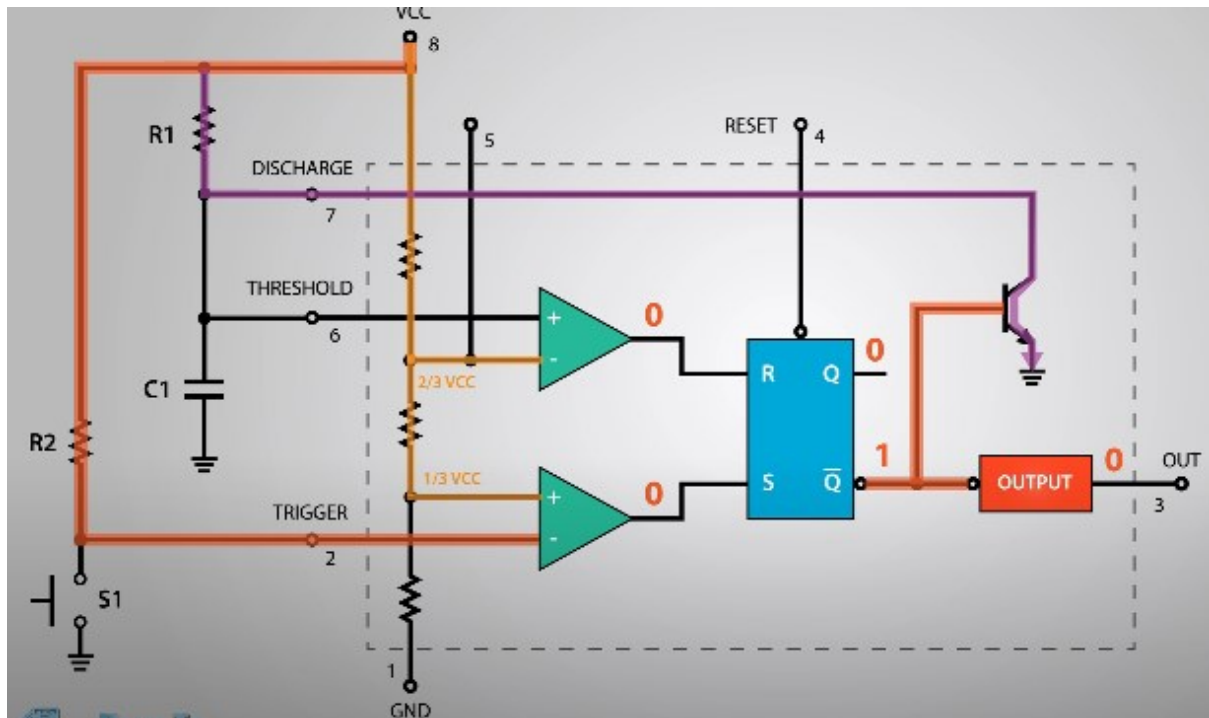


That means that the trigger comparator will output 0 to the S input of the flip-flop. On the other hand, the threshold pin is LOW and that makes the threshold comparator output 0 as well.

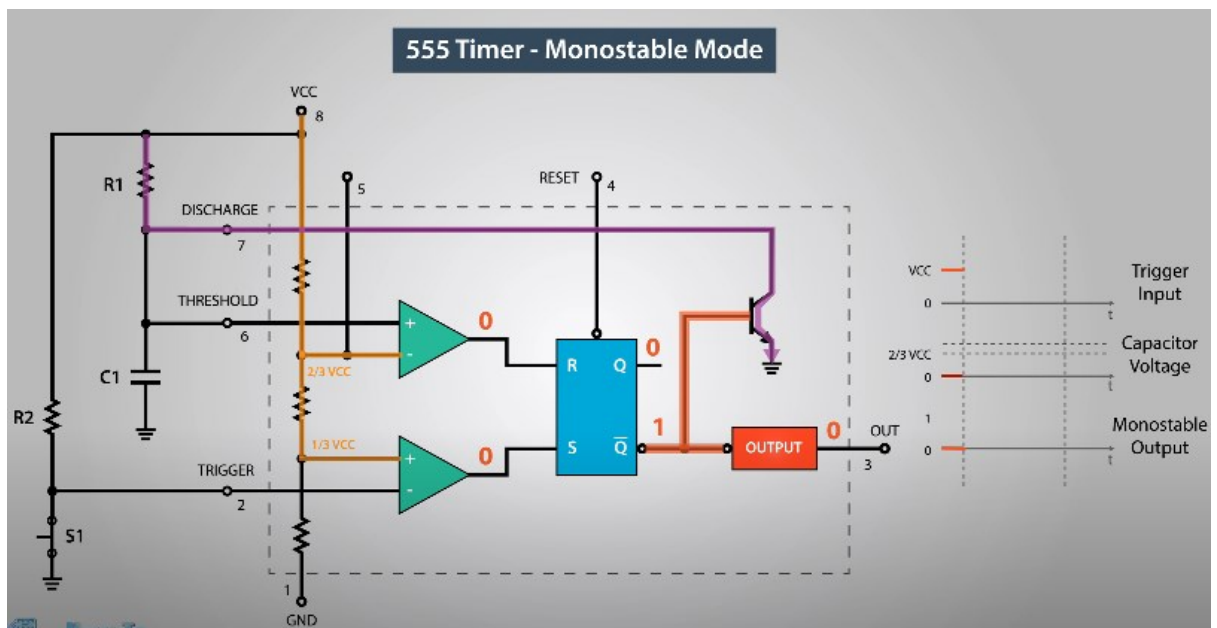


The threshold pin is actually LOW because the Q-bar output of the flip-flop is HIGH which keeps the discharging transistor active. So the voltage coming from the source is going to ground through that transistor.

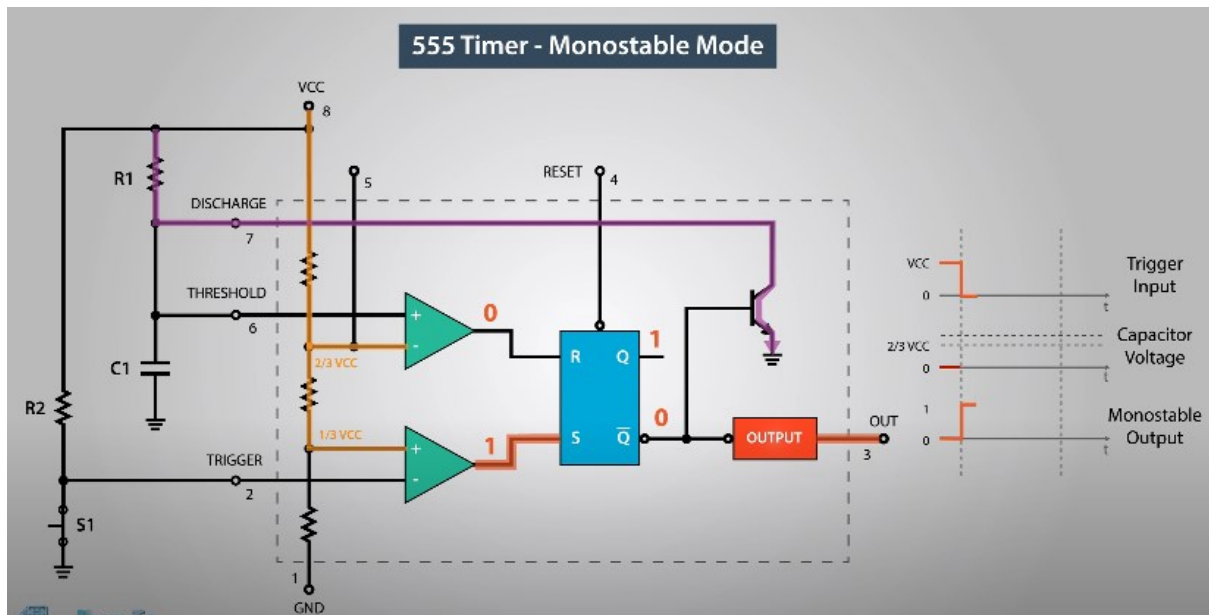




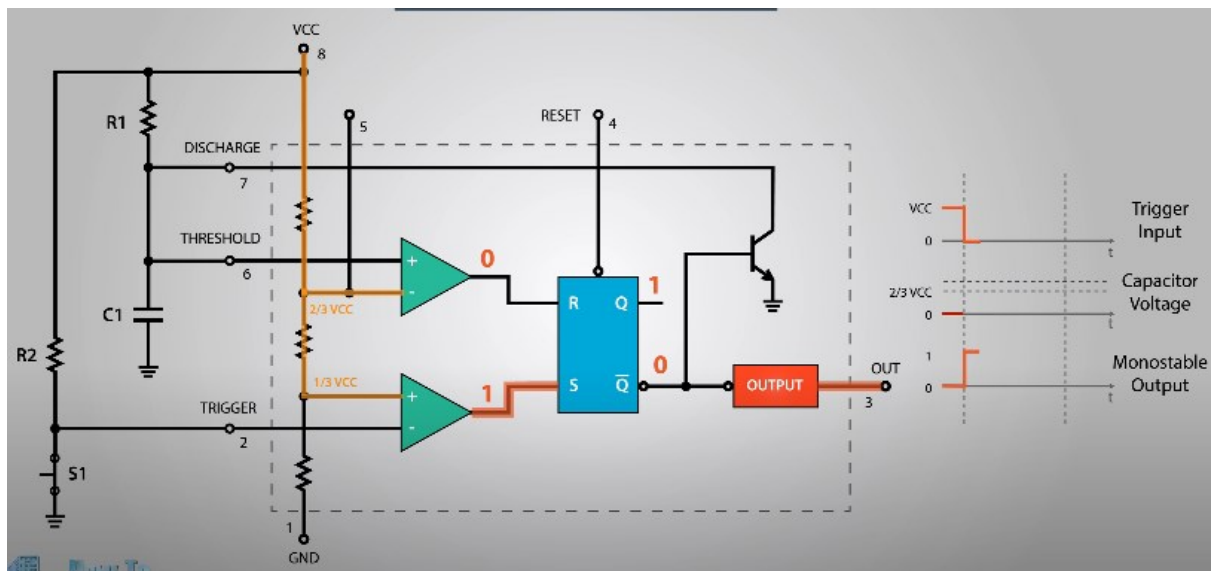
In order to change the 555 timer output state to HIGH we need to press the push button on the trigger pin.



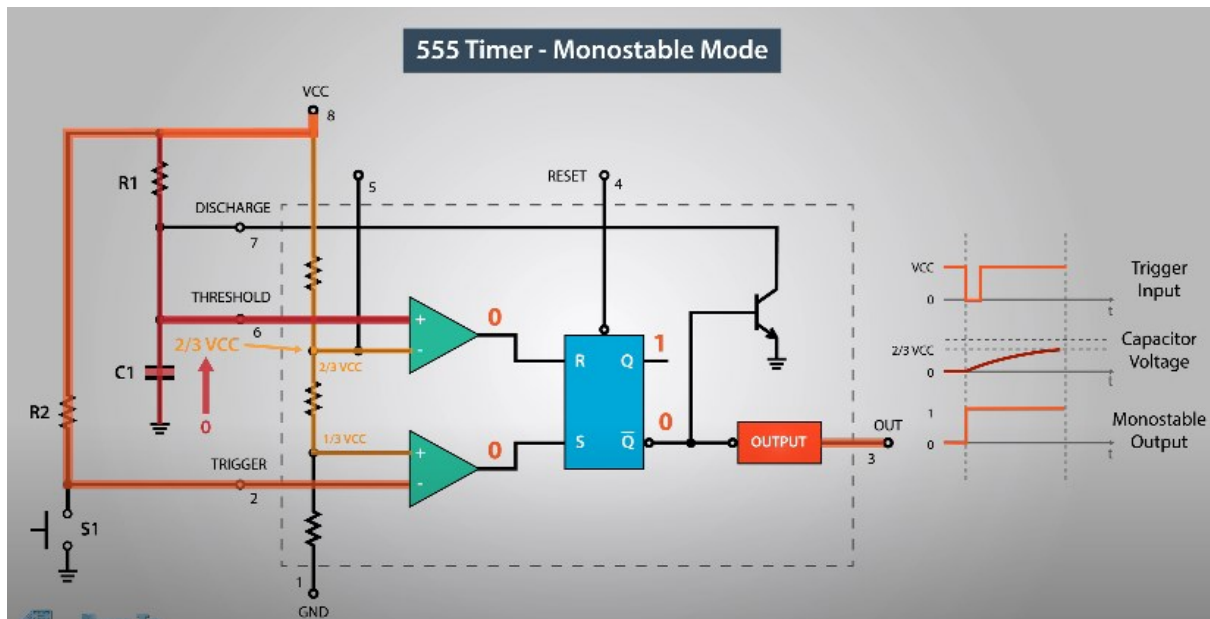
That will ground the trigger pin or the input state will be 0, thus the comparator will output 1 to the S input of the flip-flop. This will cause the Q-bar output to go LOW and the 555 timer output HIGH.



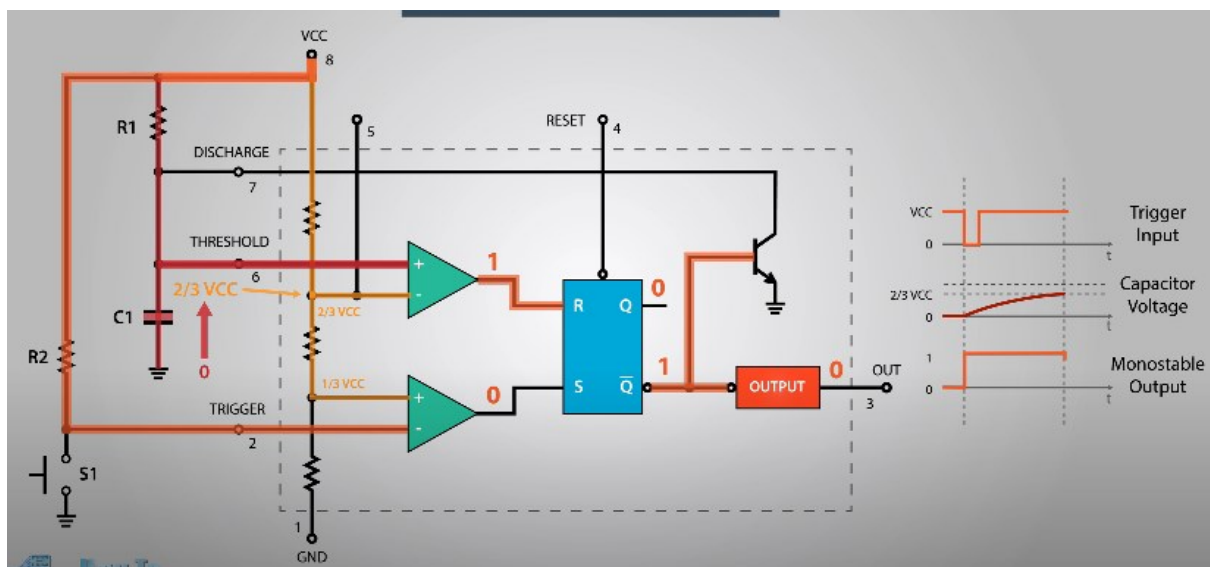
At the same time we can notice that the discharge transistor is turned off.



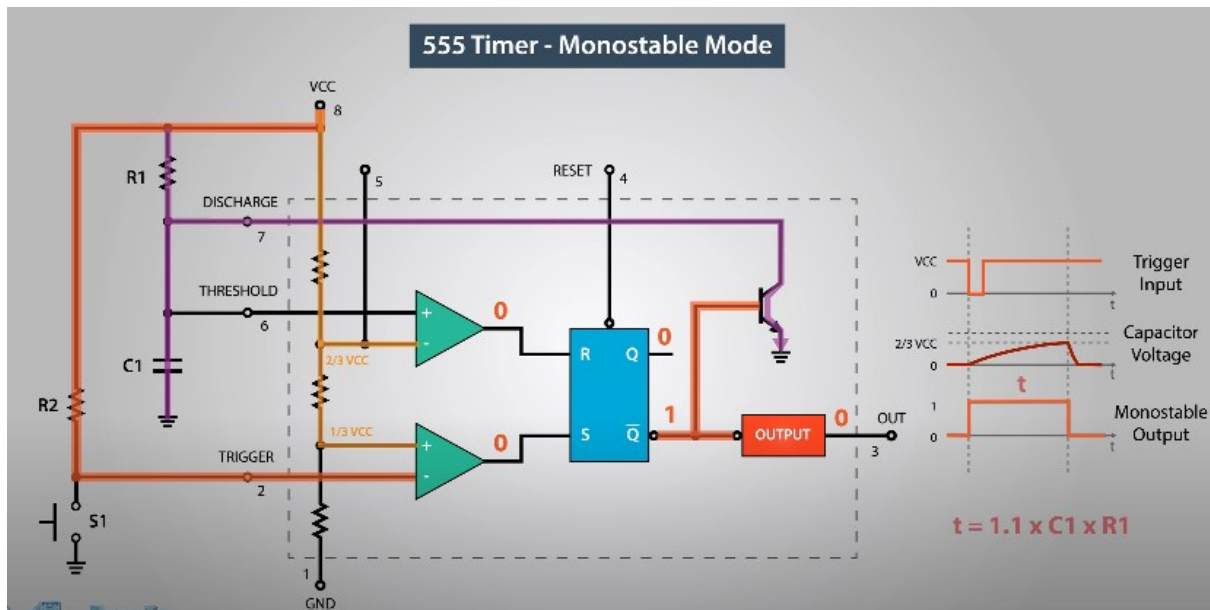
So now the capacitor C1 will start charging to the resistor R1. The 555 timer will remain in this state until the voltage across the capacitor reaches $\frac{2}{3}$ of the supplied voltage.



In that case the threshold input voltage will be higher and the comparator will output 1 to the R input of the flip-flop.



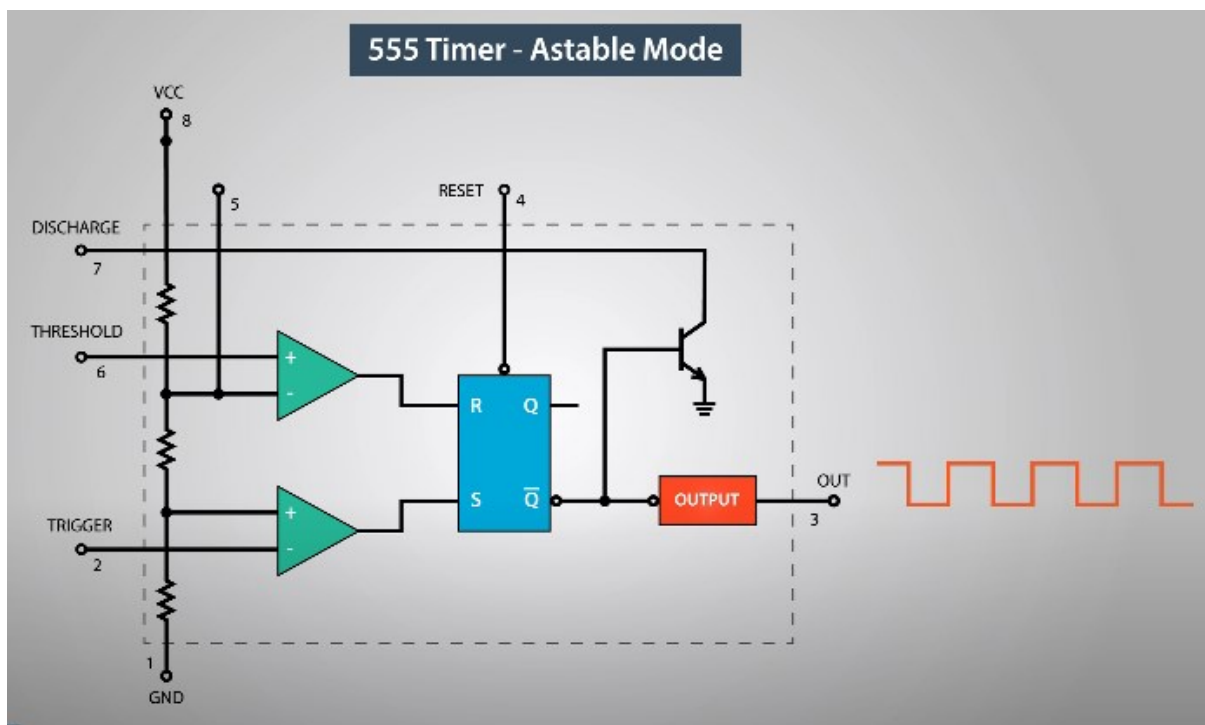
This will bring the circuit into its initial state, the Q-bar output will become HIGH which will activate the discharge transistor, as well as, make the IC output LOW again.



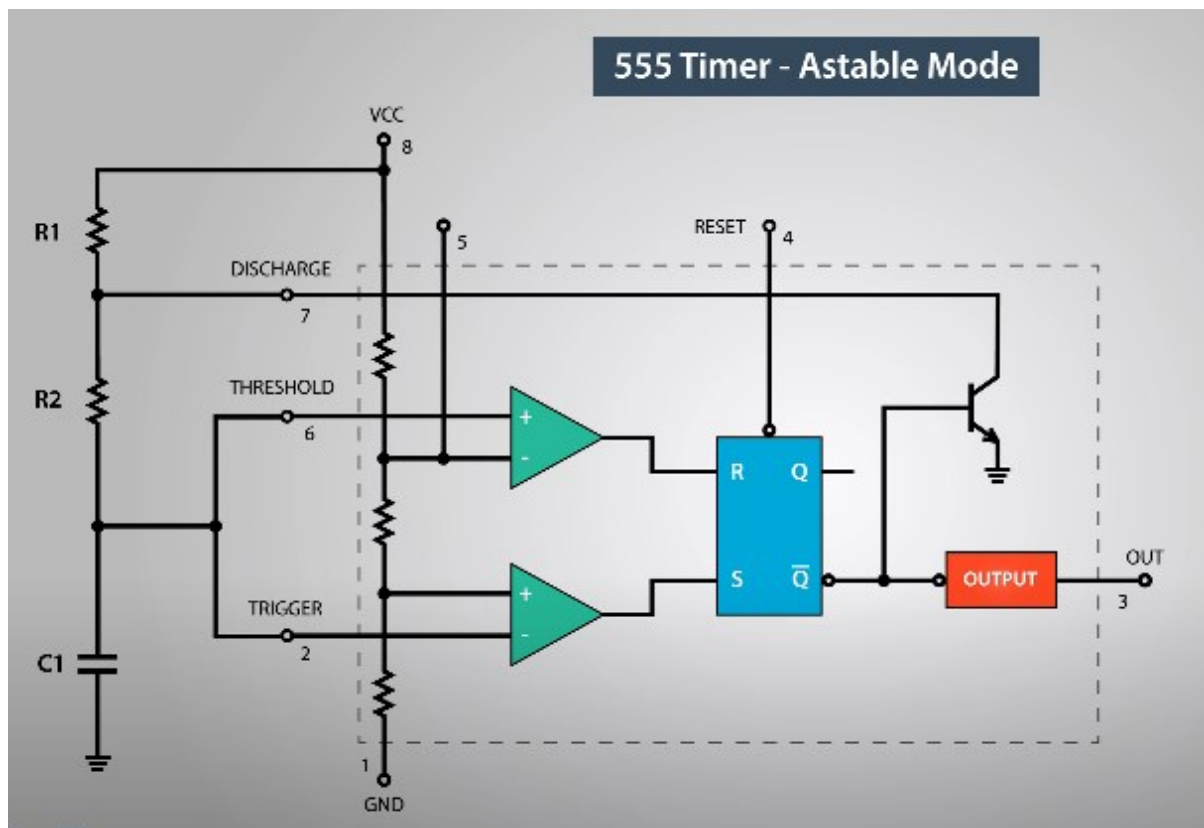
So we can notice that the amount of time the output of the 555 timer is HIGH depends on how much time the capacitor needs to charge to 2/3 of the supplied voltage and that depends on the value of both the capacitor C1 and the resistor R1. We can actually calculate this time with the following formula.

555 Timer: Astable Mode

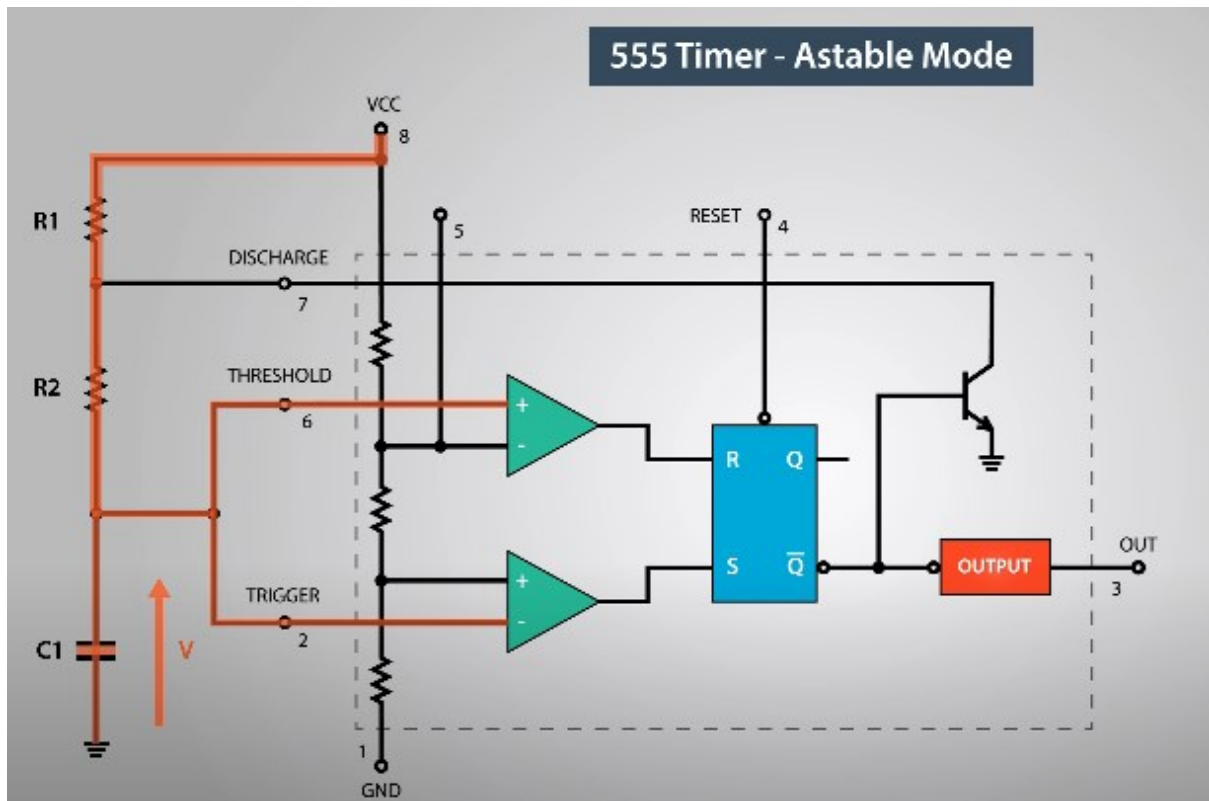
Next let's see how the 555 timer works in an astable mode. In this mode the IC becomes an oscillator or so called Free Running Multivibrator. It doesn't have a stable state and continuously switches between HIGH and LOW without application of any external trigger.



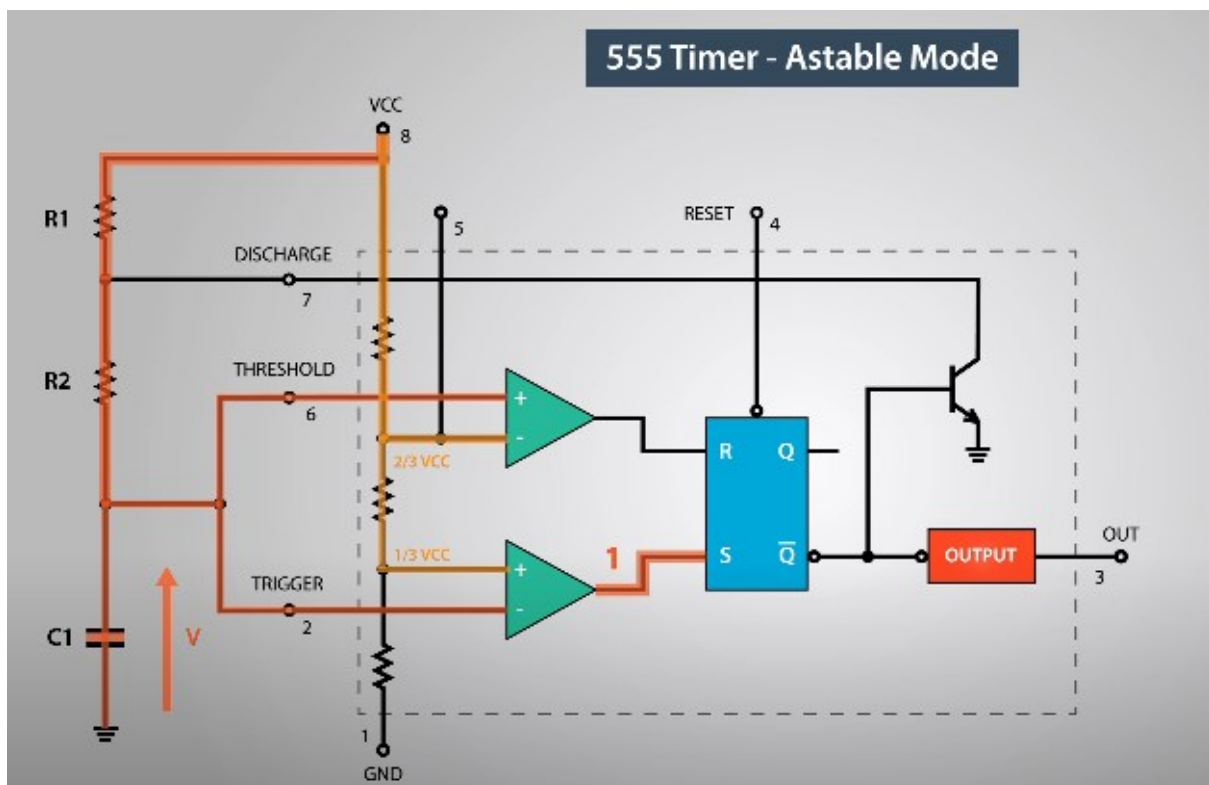
Here's an example circuit of the 555 timer operating in an astable mode. We only need two resistors and a capacitor for this example.



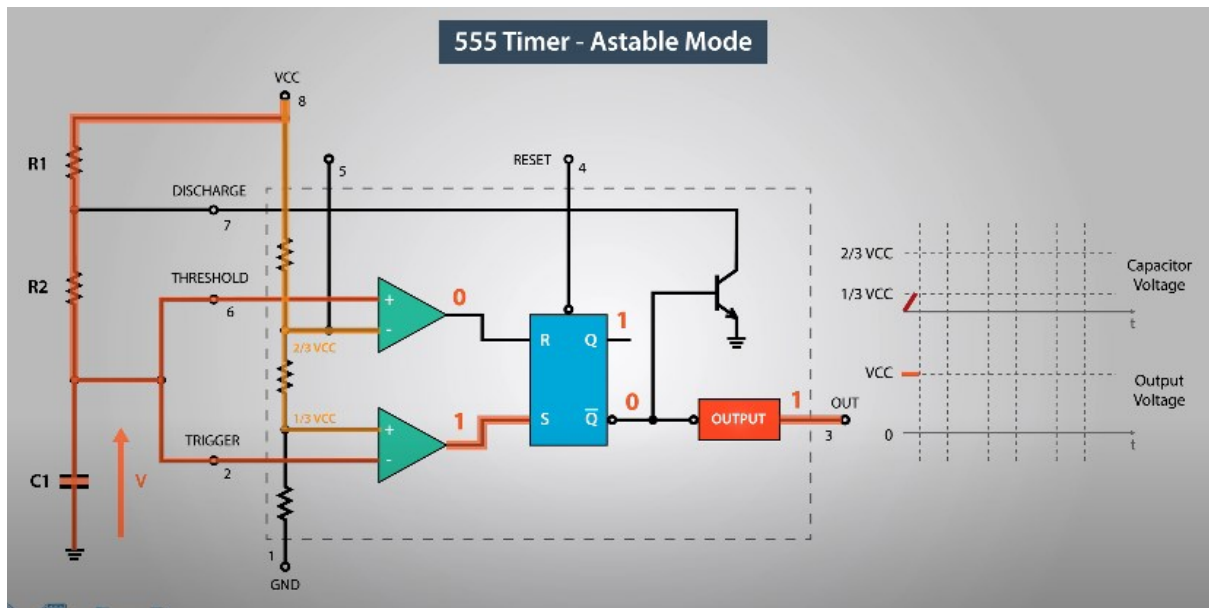
The trigger and the threshold pins are connected to each other so there is no need of external trigger pulse. Initially, the voltage source will start to charge the capacitor through the resistors R1 and R2.



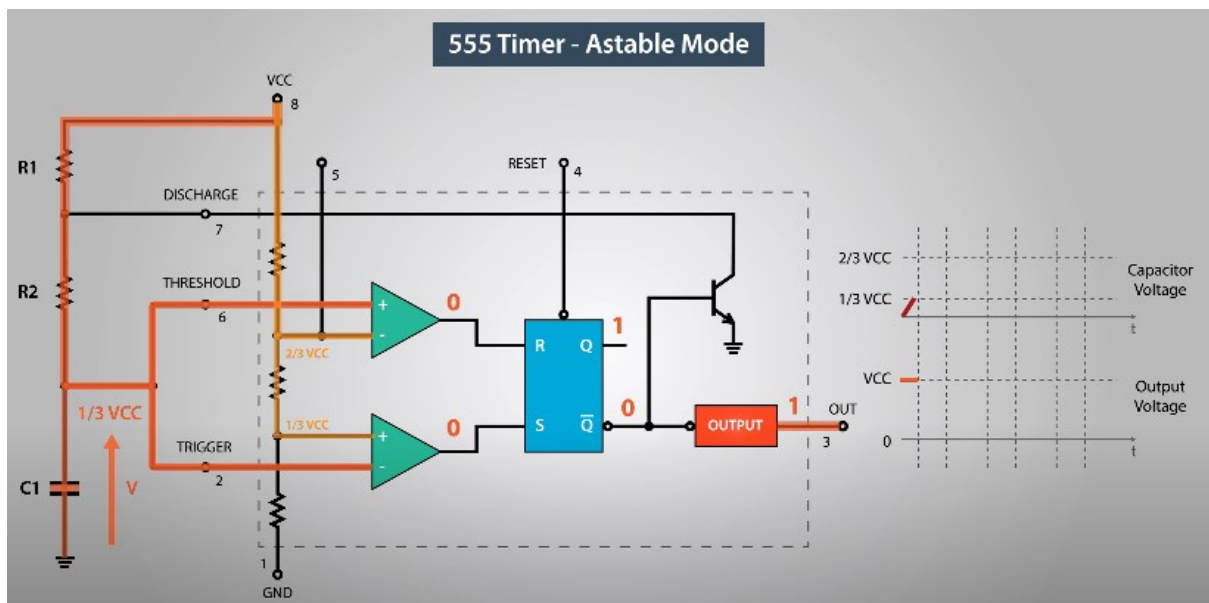
While charging the trigger comparator will output 1 because the input voltage at the trigger pin is still lower than $\frac{1}{3}$ of the supplied voltage.



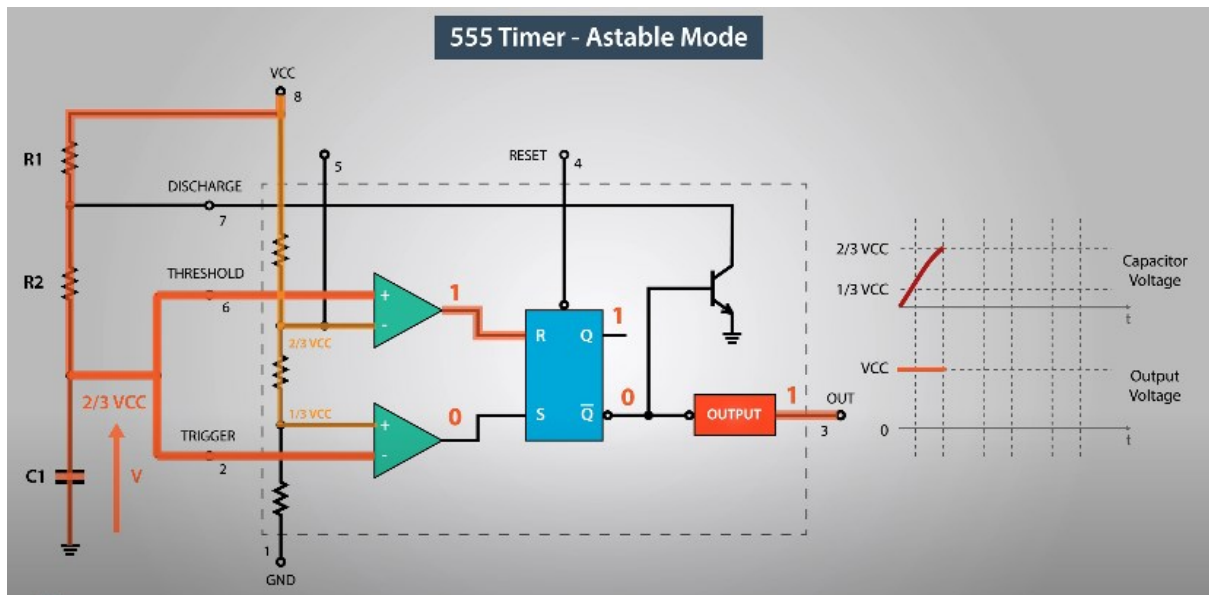
That means that Q-bar output is 0 and the discharge transistor is closed.



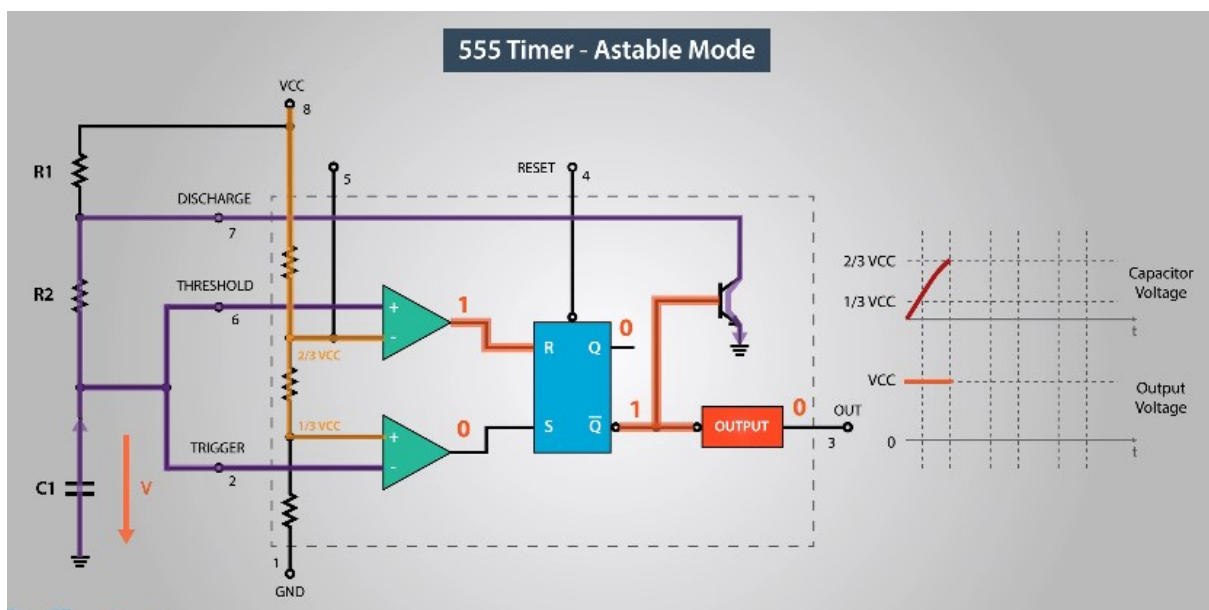
At this time the output of the 555 timer is HIGH. Once the voltage across the capacitor reaches 1/3 of the supplied voltage the trigger comparator will output zero, but at this point that won't do any change as both R and S inputs of the flip flop are 0.



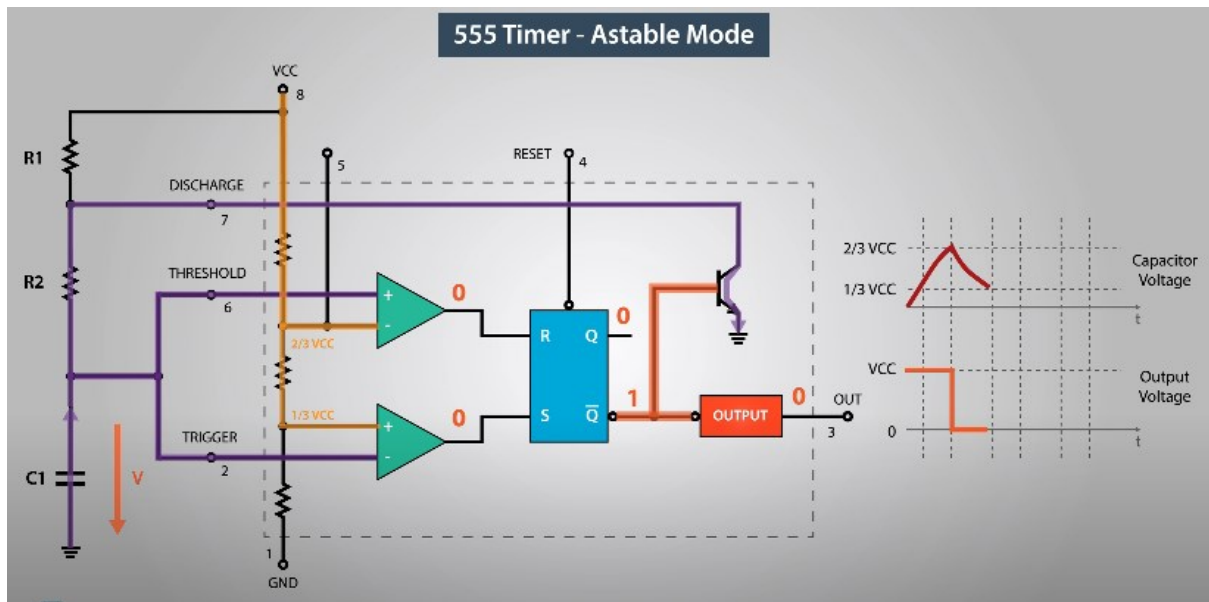
So the voltage across the capacitor will keep rising and once it reaches 2/3 of the supplied voltage the threshold comparator will output 1 to the R input of the flip-flop.



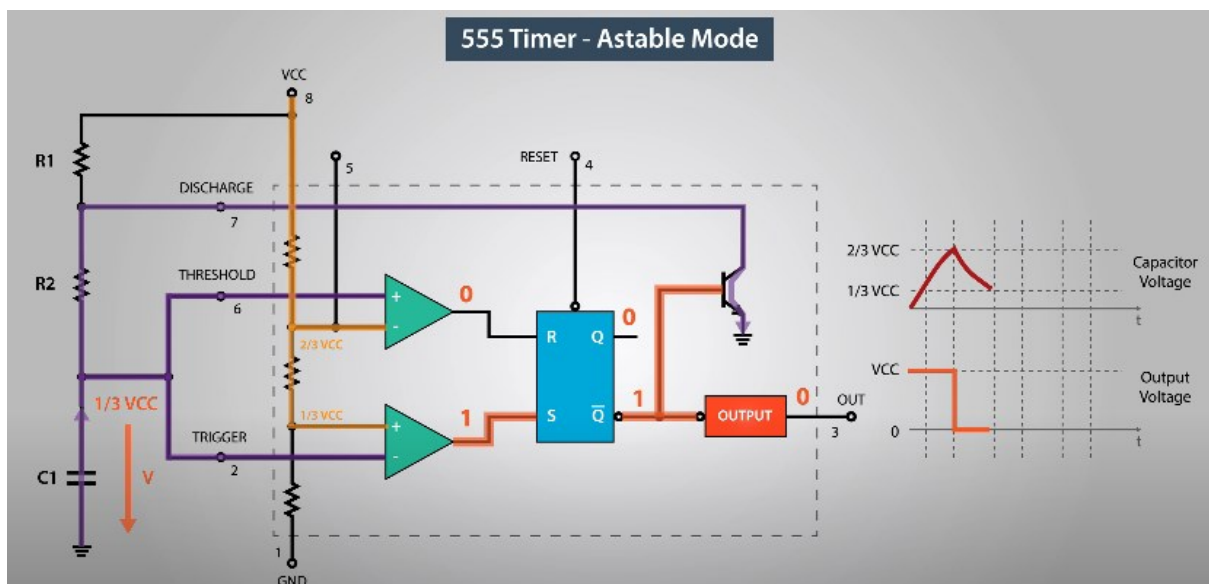
This will activate the discharge transistor and now the capacitor will start discharging through the resistor R_2 and discharging transistor. At this time the output of the 555 timer is LOW.



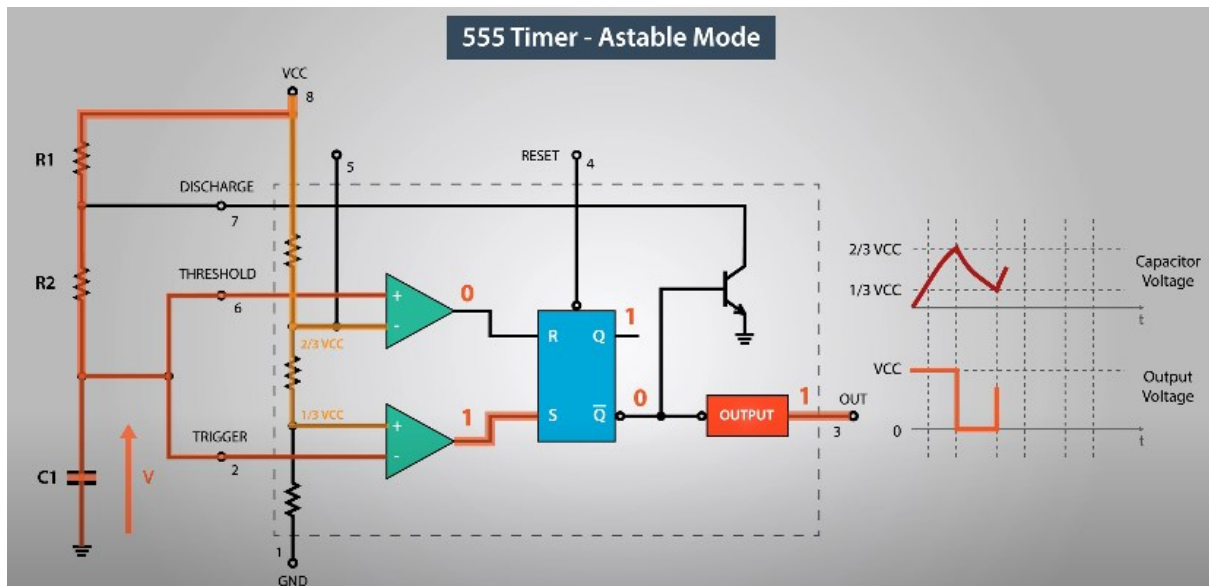
While discharging the voltage across the capacitor starts to decline and the threshold comparator right away it starts to output 0, which actually doesn't do any change as now both R and S inputs of the flip-flop are zero.



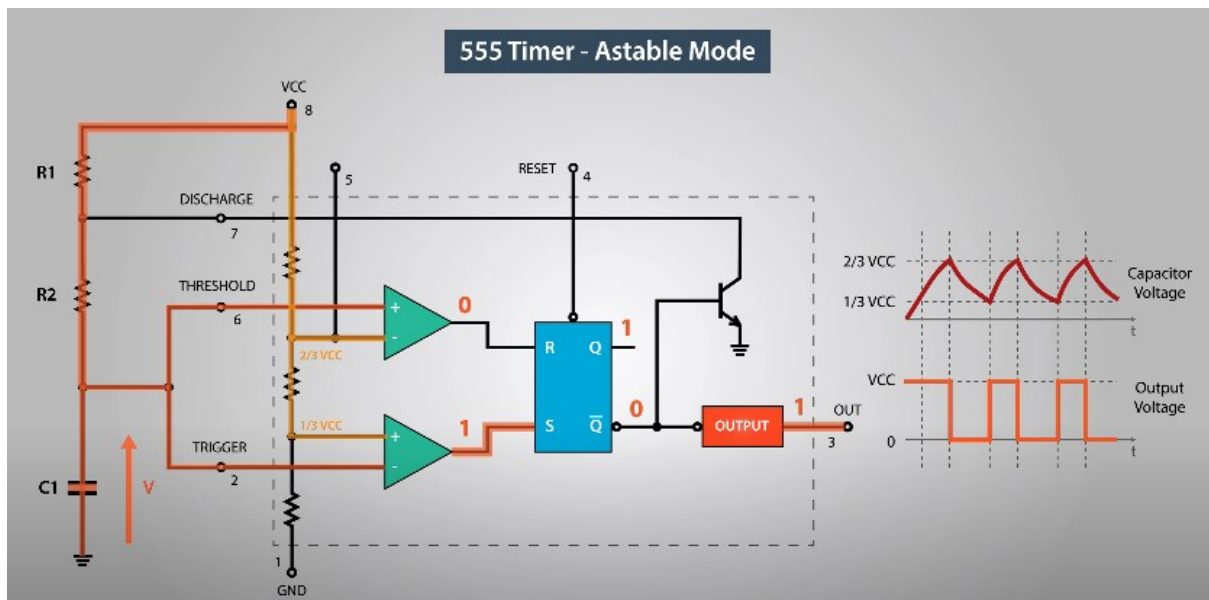
But once the voltage across the capacitor drops to $1/3$ of the supply voltage, the trigger comparator will output 1.



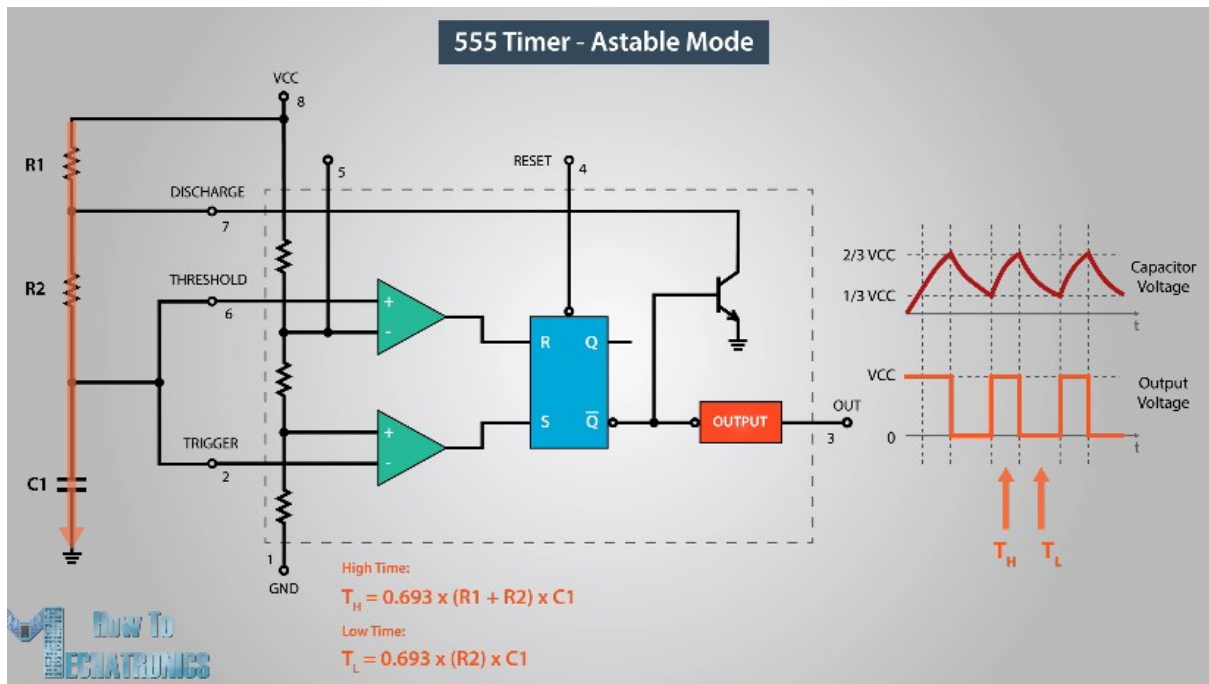
This will turn off the discharge transistor and the capacitor will start to charge again.



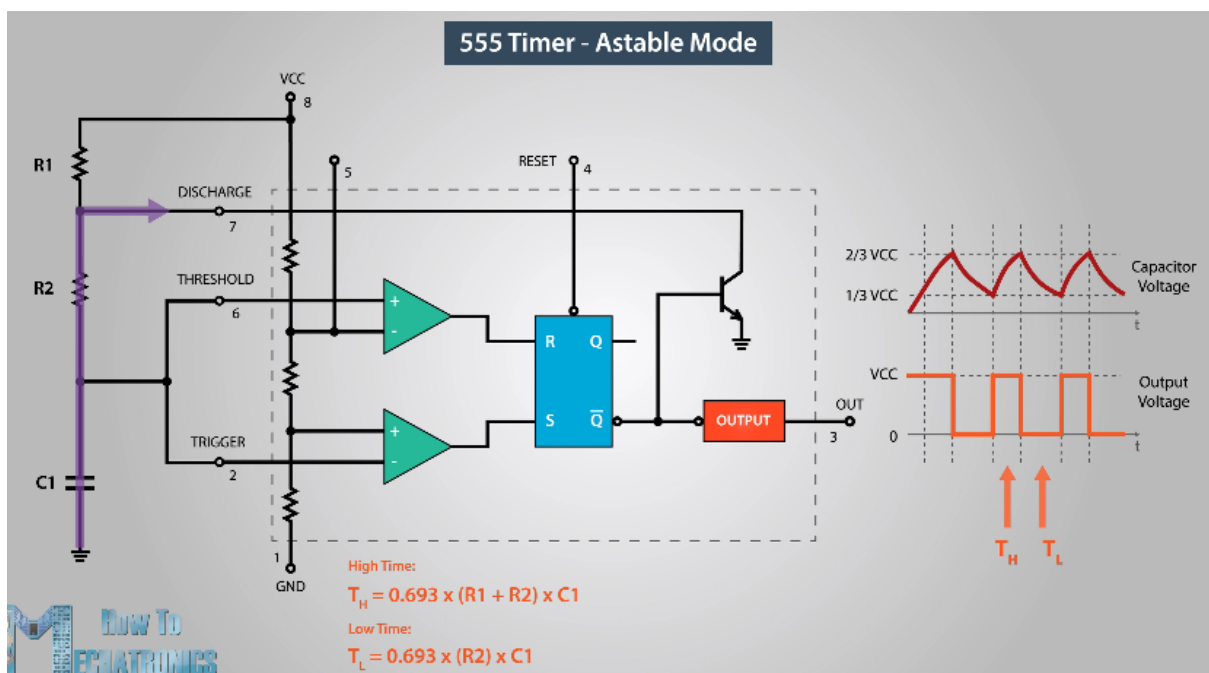
So this process of charging and discharging between $\frac{2}{3}V_{CC}$ and $\frac{1}{3}V_{CC}$ of the supplied voltage will keep running on its own, thus producing a square wave on the 555 timer output.



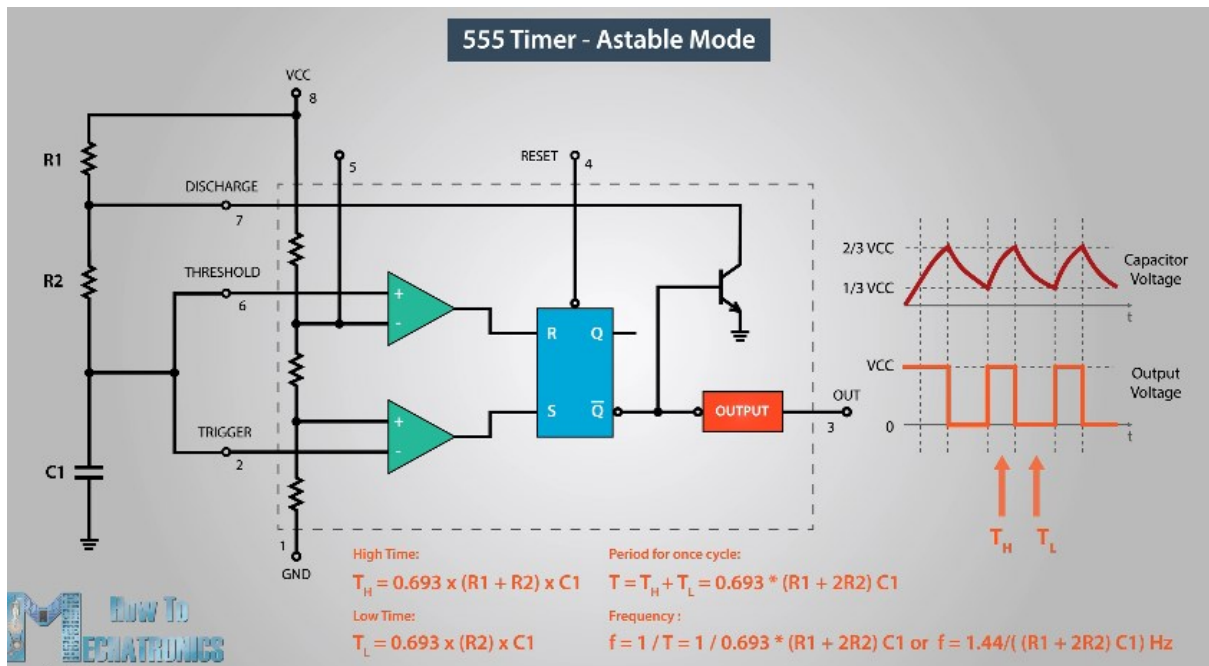
We can calculate the time the output of the IC is HIGH and LOW using the following formulas. The HIGH time depends on the resistance of both R1 and R2, as well as the capacitance of the capacitor.



On the other side, the LOW time depends only on the resistance of R2 and the capacitance of the capacitor.



So if we sum the HIGH and LOW times we will get the period of one cycle. On the other hand, the frequency is how many times this happens in one second. So $1/T$ will give us the frequency of the square wave output.



If we make some modifications to this circuit, for example, change the R2 resistor with a variable resistor or a potentiometer we can instantly control the frequency and duty cycle of the square wave.

