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RC, Transistors and 555 Timer Projects

Introduction

In this project, we will learn about the charge and discharge times of a resistor-capacitor (RC) circuit. We will then build a simple RC and LED circuit to experiment with different RC and time constant values.

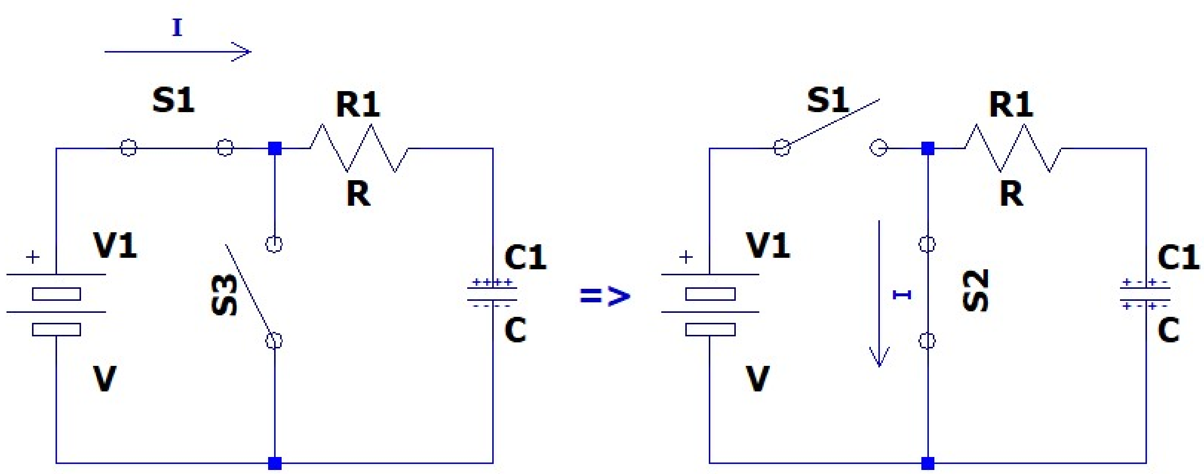
We will then introduce a transistor and a few diodes to help us increase the RC time constant as well as the brightness of the LED in our test circuit.

Lastly, we will learn about a simple integrated circuit (IC), the 555 Timer. We will learn how the charge and discharge time of an RC circuit is used in simple designs with the 555 timers to create pulses of different duration.

RC Circuits

Charge/Discharge Time of an RC Circuit

A capacitor is a passive device for storing electric charge. When an electric source like a battery is connected to a capacitor, the battery induces a current in the circuit which moves electrons from one of the capacitor's plates to the other. As the charge builds up on the capacitor's plates, the voltage across the capacitor increases until it reaches that of the battery. At that point the current and movement of charges stop.



As one can imagine, the current at the moment a battery is attached to a capacitor is the largest, and as the capacitor collects more charge, the current slows down. Eventually, once the capacitor reaches its full charge, the current comes to a stop.

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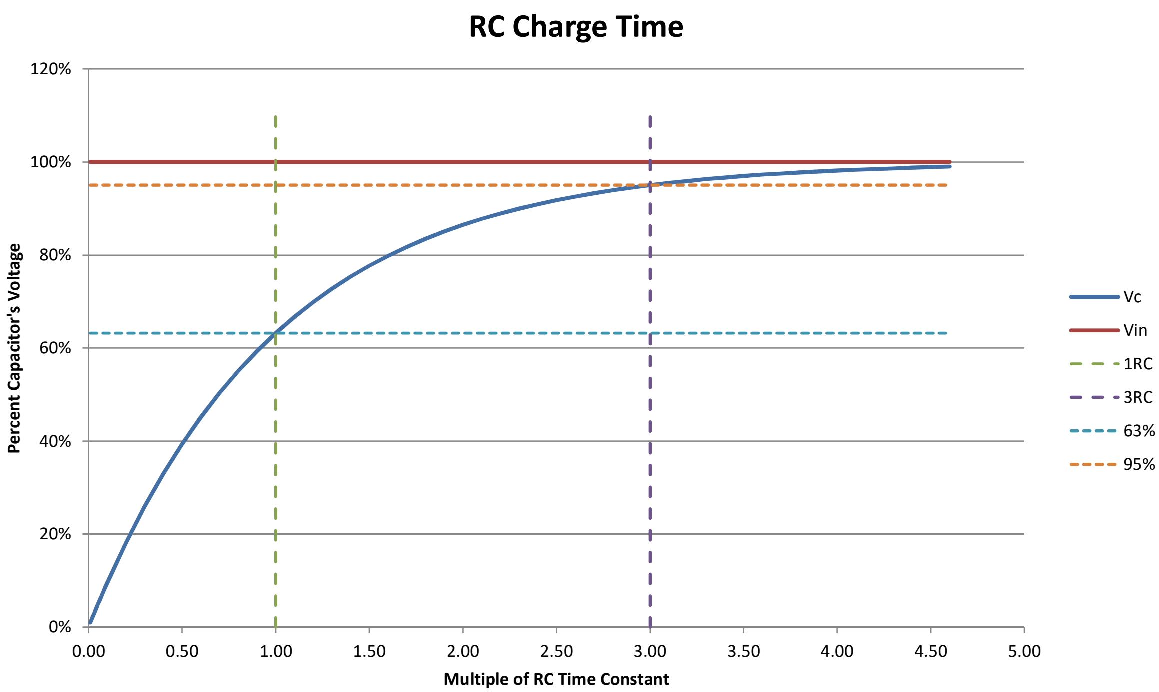
The charge and voltage build up across the capacitor follow a similar profile. At time 0, the charge, and therefore the voltage, across the capacitor are 0. The charge and voltage build up quickly at the beginning, but as the capacitor reaches its maximum charge, the charge build-up slows down.

The time it takes to charge a capacitor is a function of how large the capacitor is (its capacitance) and how large the resistance is between the battery and the capacitor. The chart below displays the charge time of a capacitor as a function of multiples of RC.



A capacitor charges to ~63% of the input voltage after a time $t_{63\%}$ = 1RC. It charges to ~95% of the input voltage after a time $t_{95\%}$ = 3RC. It follows a similar profile when discharging. In other words, a capacitor discharging through a resistor loses ~63% of its charge in a time $t_{63\%}$ = 1RC and ~95% if its charge in a time $t_{95\%}$ = 3RC.

Electrical engineers use these time constants to design RC circuits that produce very specific time durations. In the next section we learn about one such circuit.

Test Circuit

Follow the steps below to build a simple RC circuit that would allow you to turn on an LED for a time duration set by the RC values. You can experiment with different values of R to see how that would affect the RC time constant.

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A. Build the following circuit on a breadboard

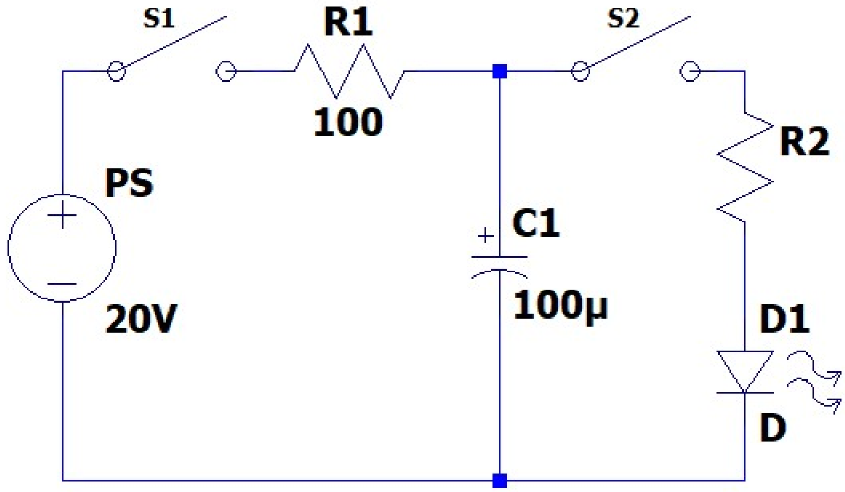

Figure 1 - Simple RC and LED Circuit

B. Once switch S1 is closed, calculate how long it would take the voltage across the capacitor C1 to reach the 95% point?

$$t_{95\%} = 3R_1C_1 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ s$$

C. If capacitor C1 has been fully charged to $V_{in} = 20V$ and the turn-on voltage (forward voltage) of the LED is $V_f = 2.2V$, what should the value of R2 be to let 8.9mA of current to flow through the LED D1?

a. What is the voltage across R2?

$$V_{R2} = V_{in} - V_f = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ V$$

b. Since the current through the LED D1 is the same as the current flowing through R2, we can find the value of R2 using Ohm's law.

$$R2 = \frac{V_{R2}}{I_{R2}} = \frac{V_{R2}}{I_f} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \Omega$$

D. Find the discharge time using the equation below.

$$t_{dis} = R_2C_1 ln\left(\frac{V_{in}}{V_f}\right) \approx 2.2R_2C_1 = \_\_\_\_\_\_\_\_\_\_\_\_ s$$

E. Experiment with resistor values larger than or smaller than what you calculated in step C above. How do they affect the delay (discharge time)?

Larger values of R2 cause the delay to …

Smaller values of R2 cause the delay to…

F. How does that affect the brightness of the LED?

G. How else can you change the delay (discharge time)?

Transistors

Transistors are active semiconductor devices that are used either as a switch or as amplifiers. Transistors usually have three leads where manipulating the voltage or current at one lead results in a larger voltage or current at the other two leads.

Bipolar Junction Transistors (BJTs)

In this lab, we will work with Bipolar Junction Transistors or BJTs. The water analogy of a BJT transistor is that of a small pipe connected to a much larger pipe through a flap “valve” (like a diode). The flap valve of the smaller pipe controls a larger flap valve in the larger pipe. As water flows in the small pipe into the larger pipe, the opening of the small flap valve causes the larger flap valve to open as well letting a much larger current to flow in the larger pipe.

A BJT transistor works on the same principle; a small electric current entering the “Base” lead of the transistor results in a much larger current flowing from the “Collector” lead to the “Emitter” lead (the larger pipe). The ratio of the collector-emitter current to the base current is the amplification parameter of a BJT transistor.

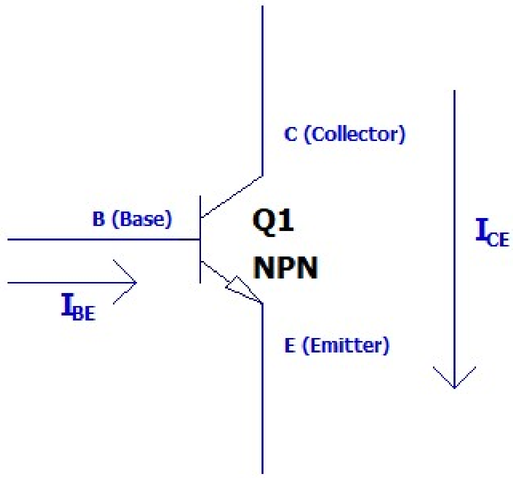

Figure 2 - Bipolar Junction Transistor (BJT)

In the next section, we will use a BJT in our circuit from the previous section to increase the time constant without affecting the brightness of the LED.

Test Circuit

Modify your RC-LED circuit to construct the one shown in Figure 3.

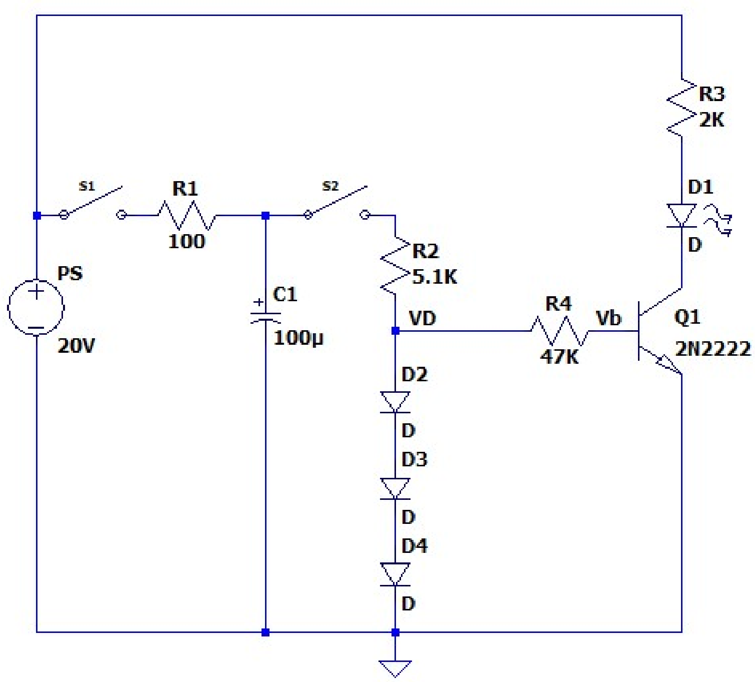

Figure 3 -Simple Delay Circuit with a BJT

The three diode combination (D2, D3 & D4) sets the voltage across the three diodes to 2.1V (3 x 0.7V).

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A. Given that Vb = 0.7V, what is the current flowing through R4 and into the base of the transistor Q1?

$$I_b = \frac{V_{R4}}{R_4} = \frac{V_D - V_b}{R_4} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ A$$

B. This small current into the base of the transistor gets amplified by the transistor by ~200. What is the current flowing through the collector and emitter of the transistor and therefore the LED?

$$I_{CE} = I_{LED} = 200 I_b = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ A$$

Note: This current turns on the LED at an acceptable brightness.

C. If C1 is fully charged to 20V, what is the current flowing through R2 as the capacitor discharges?

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{V_{C1} - V_D}{R_2} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ A$$

Note: Since this current is much larger than I_b, the discharge time is primarily determined by R_2C_1 combination.

D. Find the discharge time using the equation below.

$$t_{dis} = R_2C_1 ln\left(\frac{V_{in}}{V_D}\right) \approx 2.2R_2C_1 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_ s$$

E. Experiment with resistor values larger than or smaller than 5.1K. How do they affect the delay (discharge time)?

Larger values of R2 cause the delay to …

Smaller values of R2 cause the delay to…

F. How do these affect the brightness of the LED?

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555 Timer IC

The 555 timer IC is a highly stable device for creating accurate time pulses. In the "Single Pulse" mode of operation, the time is precisely controlled by one external resistor and capacitor. To operate as an oscillator (pulse train), the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor.

The block diagram of the device is given below in Figure 4.

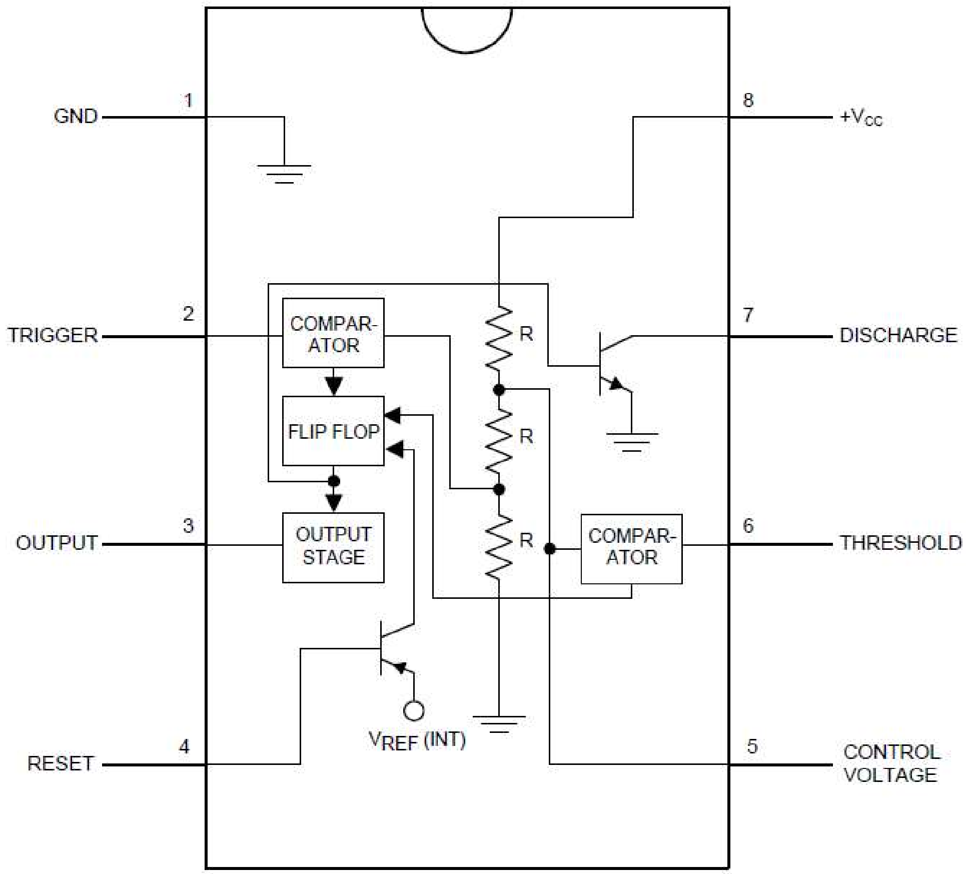

Figure 4 - 555 Timer Block Diagram

The 555 Timer's two "comparator inputs "Trigger" (pin 2) and "Threshold" (pin 6) control the output (pin 3) of the chip. When the Trigger pin is set to low (less than 1/3Vcc), the output of the chip is set to high (Vcc). Additionally, the transistor connected to the "Discharge" pin (pin 7) is turned off.

If, on the other hand, the voltage input on the Threshold is set to high (greater than 2/3Vcc), the output is set to low (0V) and the Discharge transistor is turned on.

The 555 Timer can be operated in two modes: 1) Mono-stable or one shot and 2) Astable or periodic.

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Mono-Stable Operation

In this mode of operation (Figure 5), the timer functions as a one-shot, creating a single pulse. The external capacitor is initially held discharged by a transistor inside the timer. Upon setting the Trigger input (pin 2) to less than 1/3 Vcc to, the flip-flop is set which both releases the short circuit across the capacitor and drives the output high.

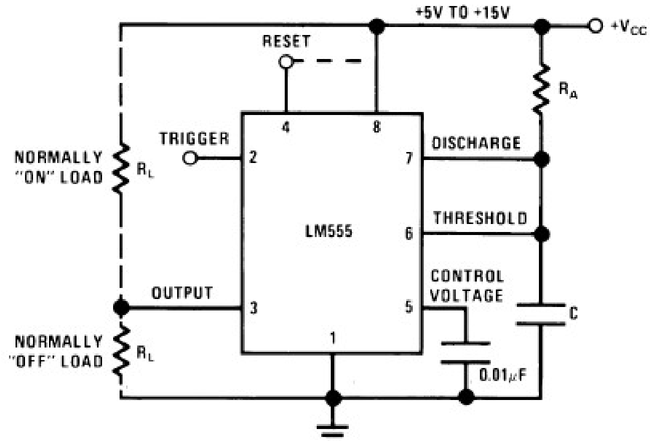

Figure 5 - Mono-stable Operation

The time that it takes the capacitor to charge to the "Threshold" voltage, 2/3Vcc, is given by

$$t = 1.1R_A C \quad \textbf{Eq. 1}$$

The comparator then resets the flip-flop which in turn discharges the capacitor and drives the output to its low state.

Astable Operation

If the circuit is connected as shown in Figure 6 (pins 2 and 6 connected) it will trigger itself and free run as an oscillator (pulse train). In this mode of operation, the capacitor C charges and discharges between 1/3 VCC and 2/3 VCC. The external capacitor (C) charges through R_A + R_B; and therefore, the charge time is given by

$$t_1 = 0.693(R_A + R_B)C \quad \textbf{Eq. 2}$$

The capacitor discharges, on the other hand, through R_B. The discharge time is, therefore, given by

$$t_2 = 0.693R_B C \quad \textbf{Eq. 3}$$

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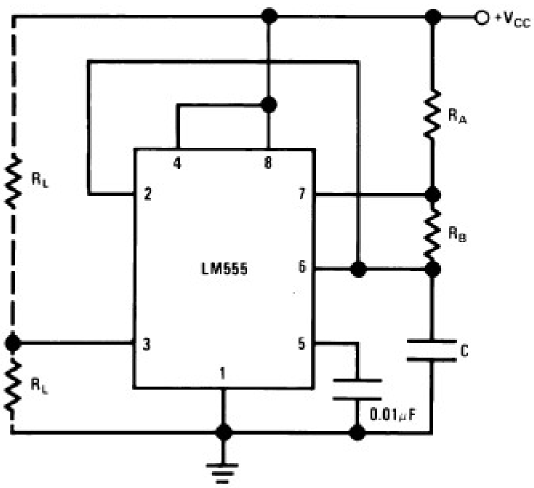

Figure 6 - Astable Operation

Thus, the duty cycle may be precisely set by the ratio of these two resistors.

In the next section, we will go through step by step construction of an oscillator circuit.

Circuit Construction

Using a 555 Timer IC, resistors, capacitors and an LED, we will construct a simple timing circuit that will blink an LED indefinitely. Choosing the on and off times for the LED will determine the R and C values in the circuit. The following steps will walk us through determining the R and C values and the construction the circuit shown in Figure 7.

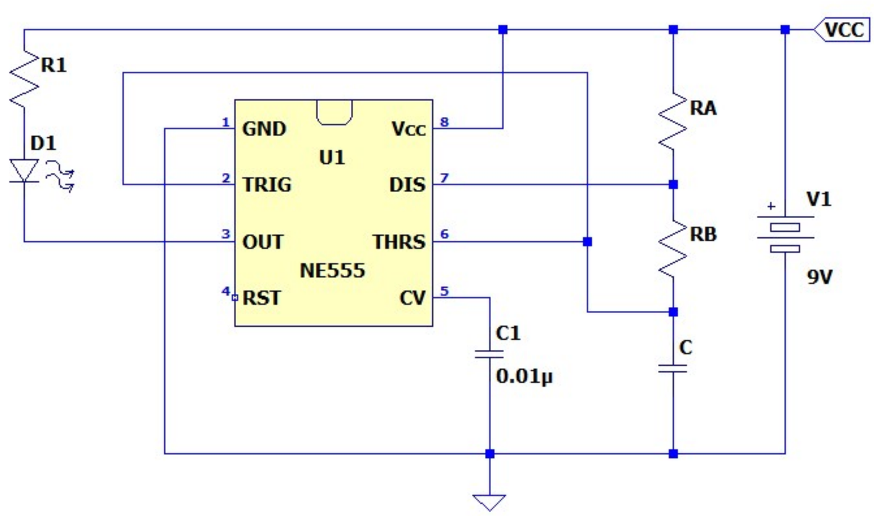

Figure 7 - 555 Timer Circuit

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Connecting the LED

We would like for the LED to turn on when the output is low; therefore, we connect the LED and its current limiting resistor from the power (Vcc) to the output (pin 3).

A. Given the turn-on voltage of the LED ($V_f = 2.2V$) and a desired LED current of $I_f = 10ma$, determine the current limiting resistor for your LED.

$$R_1 = \frac{V_{cc} - V_f}{I_f} = \frac{9 - 2.2}{0.010} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\Omega$$

Setting the Pulse Durations

In this portion of the project, we will determine the R & C values for the timer circuit such that the LED blinks for the time durations of our choosing.

A. The LED is on when the output (pin 3) is low. This happens when the voltage on the threshold input (pin 6) has risen above 2/3Vcc. It remains on until the voltage on the trigger input (pin 2) falls below 1/3Vcc. This is during the time that the capacitor is discharging through R_B and the discharge pin (pin 7). Pick a time duration for which the LED should remain on

$$t_2 = \_\_\_\_\_\_\_\_\_\_\_\_\_\_ s$$

B. Recall that in astable operation, the discharge time is given by Eq. 3

$$t_2 = 0.693 R_B C$$

a. Using this equation, we can solve for either R_B or C. Let's solve for R_B.

$$R_B = \frac{t_2}{0.693C}$$

b. Now, let's pick a convenient value for C

$$C = 100\mu F$$

c. Now we can solve for the value of R_B

$$R_B = \frac{t_2}{0.693 \times 100 \times 10^{-6}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\Omega$$

C. The LED is off when the output (pin 3) is high. This happens when the voltage on the trigger input (pin 2) has fallen below 1/3Vcc. It remains low until the voltage on the threshold input (pin 6) rises to 2/3Vcc. This is during the time that the capacitor is charging through R_A and R_B. Pick a time duration t_1 ($> t_2$) for which the LED should remain on

$t_1 =$ ______________s

D. Recall that in astable operation, the discharge time is given by Eq. 2

$$t_1 = 0.693(R_A + R_B)C$$

a. Using this equation, we can solve for either R_A.

$$R_A = \frac{t_1}{0.693C} - R_B$$

b. Using the values for t_1, R_B and C, we can now find the value of R_A

$$R_A = \frac{t_1}{0.693 \times 100 \times 10^{-6}} - R_B = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \Omega$$

E. Construct the circuit in Figure 7 with the resistor and capacitor values above and test the circuit.

Observations

1. Is the circuit behaving as you expected? If not, why not?

2. How would you change circuit to have the LED stay on for twice the amount of time?

3. What do you think is the maximum time duration you can make the LED stay on?