555 Timers – Astable Operation
Cornerstone Electronics Technology and Robotics II

- **For 555 Timers – Introduction, see:** http://cornerstonerobotics.org/curriculum/lessons_year2/erii5_555_timer.pdf
- **For 555 Timers – Monostable Operation, see:** http://cornerstonerobotics.org/curriculum/lessons_year2/erii5_555_timer_monostable_operation.pdf
- **Basic Astable Operation:**
  - Definition of oscillate: to move back and forth at a constant rate between two points, for example, a swinging pendulum.
  - Astable means the circuit will continue to oscillate once power is applied. The 555 timer astable operation creates an on-off oscillation effect, generating a square waveform output. The oscillator frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor.
  - Simplified Astable Operation Explanation:
    - In Figure 1, C1 charges through R1 and R2 and the 555 timer acts as an open switch (Figure 1).
    - When the voltage across C1 reaches 2/3 V_{CC}, the 555 timer acts as an electronic switch, shorting R2-C1 to ground (Figure 2). C1 discharges through R2.
    - When C1 discharges to 1/3 V_{CC}, the switch opens and another charging cycle starts again.
    - When C1 is charging, the 555 output is HIGH; while C1 is discharging, the 555 output is LOW (Figure 3).

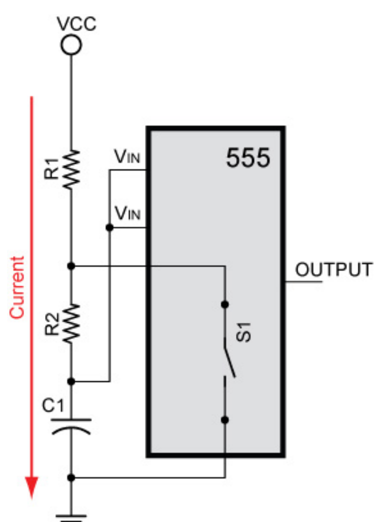


Figure 1, C1 Charging Through R1 & R2

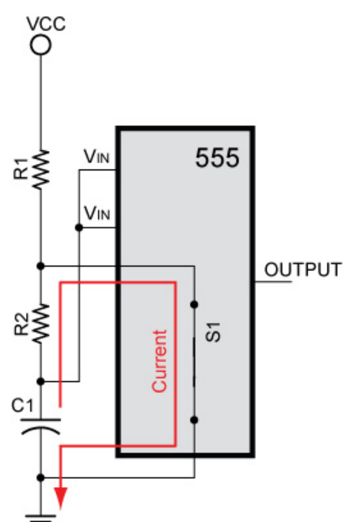


Figure 2, C1 Discharging through R2

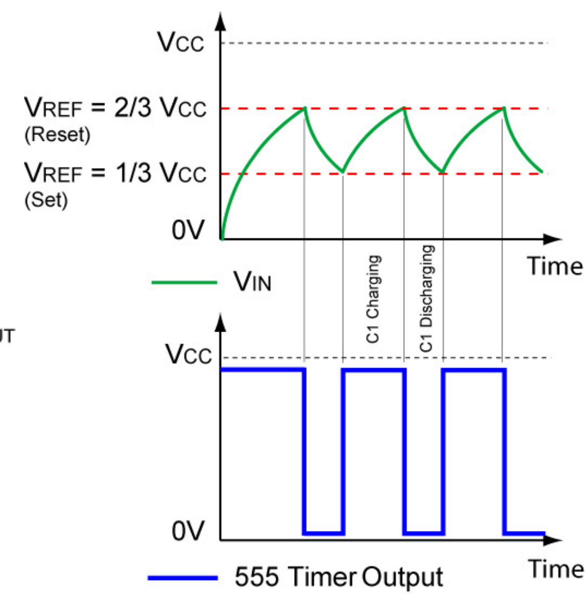


Figure 3 – Voltage at C1 and 555 Timer Output

- **Detailed Presentation of 555 Timer Astable Operation (Figures 3 – 12):**
    - A review of comparator operations follows this section.

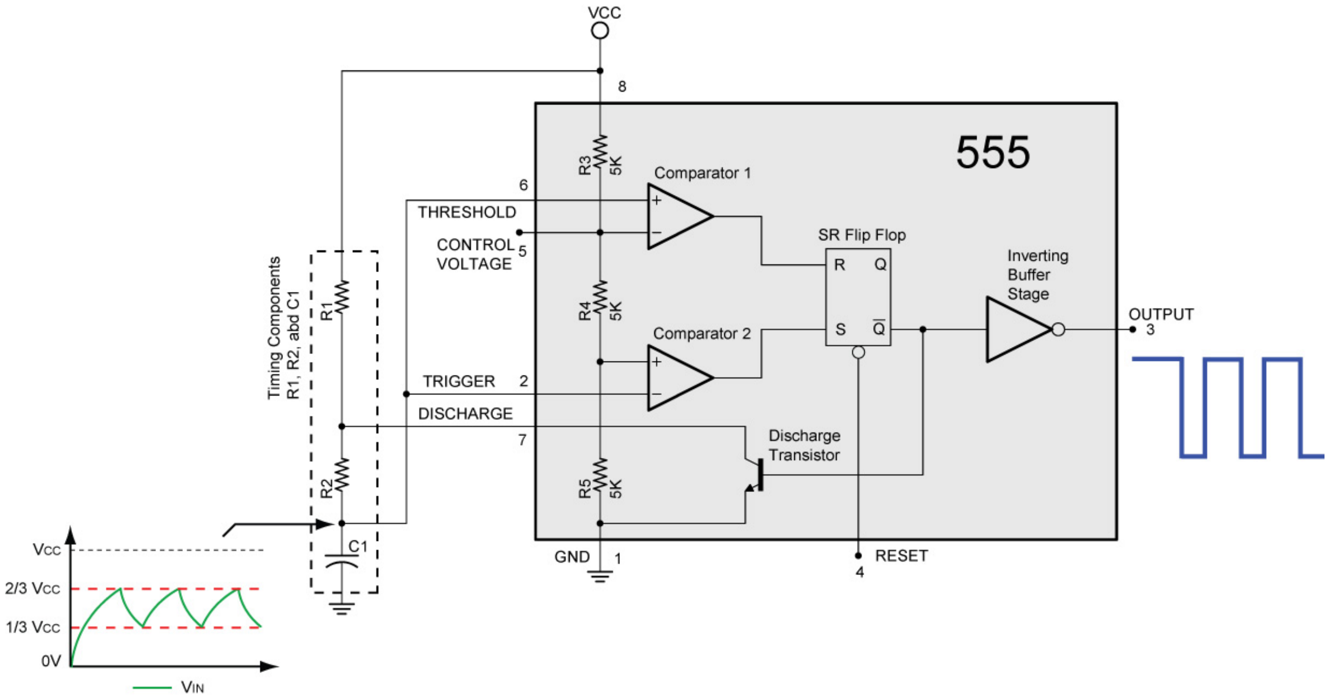
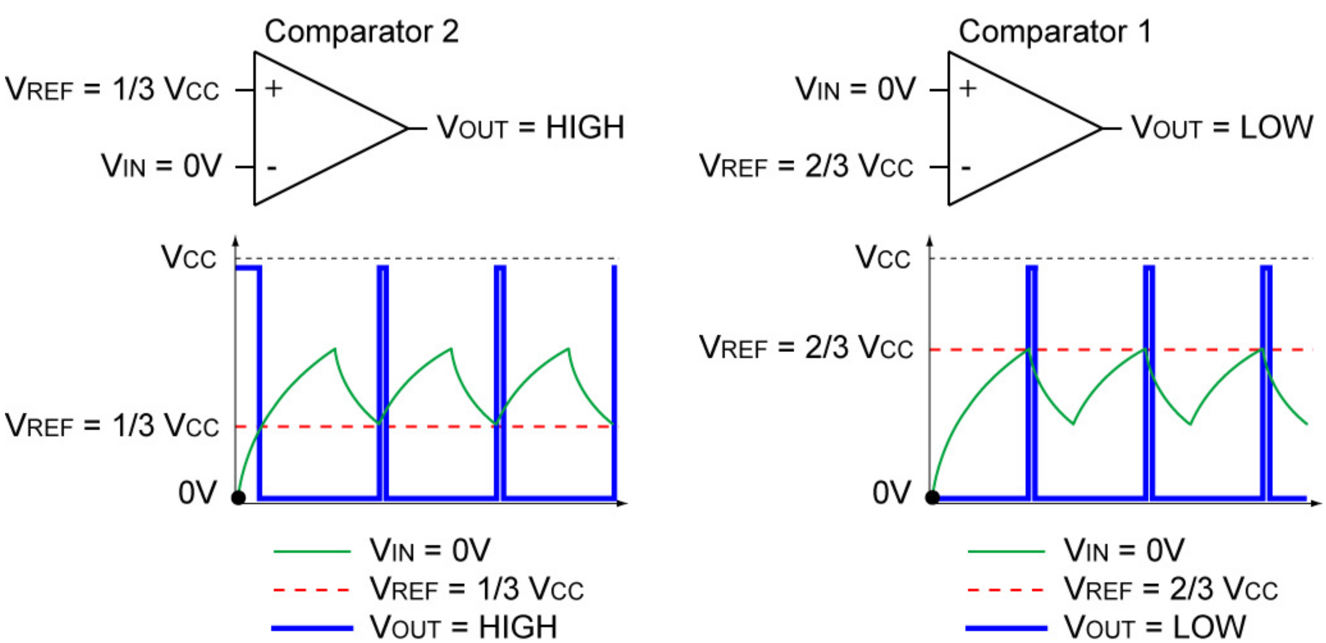


Figure 3 – 555 Timer Set Up for Astable Operation

- **Charging:**
    1. When the power is turned on, capacitor C1 is not charged and pin 2 (TRIGGER) and pin 6 (THRESHOLD) voltage (V_{IN}) is at 0 V.
    2. The output of lower comparator 2 (inverting) is therefore HIGH (V_{IN} < 1/3 V_{CC}) and the output of the upper comparator 1 (non-inverting) is LOW (V_{IN} < 2/3 V_{CC}).



Output of Lower Comparator 2 is HIGH **Output of Upper Comparator 1 is LOW**

Figure 4 – Output of Comparator 1 and 2 When Power Is Turned On

3. Comparator 2 serves as input S (Set) and comparator 1 serves as the R input (Reset) for the SR flip flop (also called a RS flip-flop). From the truth table below for a SR flip-flop, S input is HIGH and R is LOW, therefore the output $\overline{Q}$ of the SR flip-flop is LOW and the 555 timer OUTPUT is HIGH due to the inverting buffer stage.

SR Flip-Flop Truth Table			
Inputs		Outputs	
S	R	Q	$\overline{Q}$
0	0	No Change	
0	1	0	1
1	0	1	0
1	1	Undefined	

Table 1 – SR Flip-Flop Truth Table

4. Since $\overline{Q}$ is LOW, the discharge transistor is turned off and C1 begins charging through R1 and R2. While the capacitor C1 is charging, the OUTPUT of the 555 timer is HIGH; while the capacitor C1 is discharging, the OUTPUT of the 555 timer is LOW.

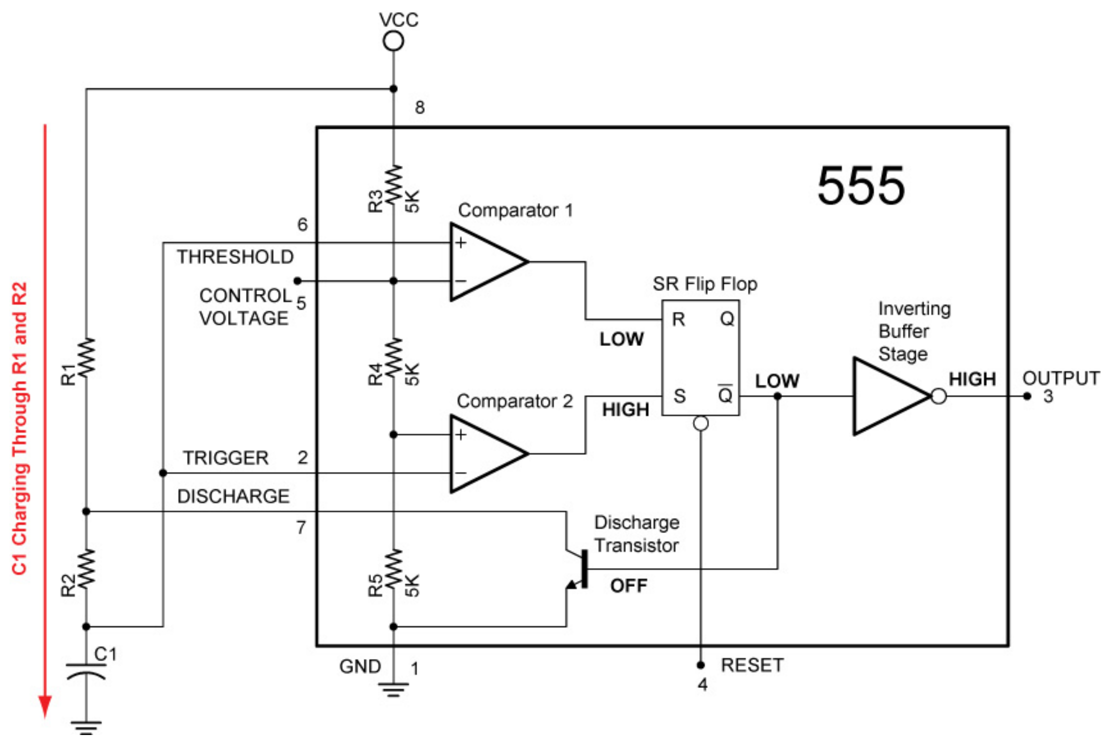
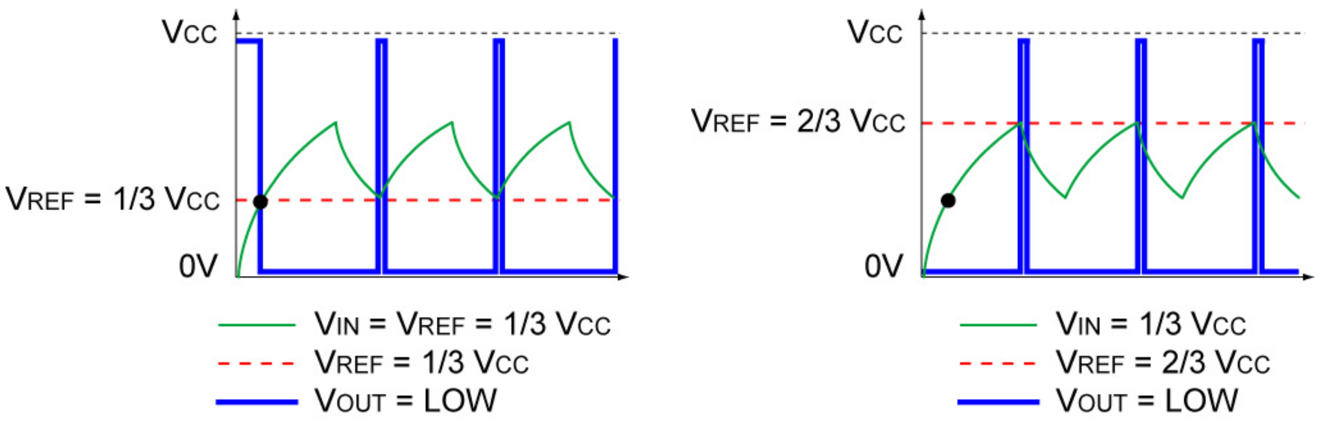


Figure 5 – C1 Charging Through R1 and R2

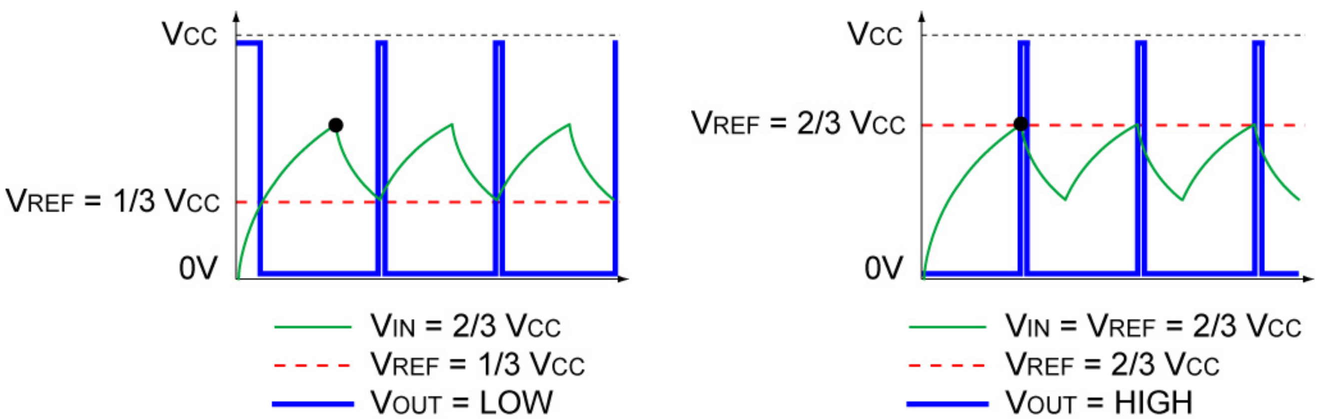
5. When the voltage across C1 (V_{IN}) reaches 1/3 V_{CC}, the output of the lower comparator 2 changes to LOW; comparator 1 remains unchanged.



Output of Comparator 2 Changes to LOW **Output of Comparator 1 Remains LOW**

Figure 6 – Output Comparator 1 and 2 When V_{IN} Reaches 1/3 V_{CC}

6. From the SR flip-flop truth table, the output $\overline{Q}$ of the SR flip-flop does not change (S=0 & R=0), thus remaining in a LOW state.
7. C1 continues to charge until it reaches 2/3 V_{CC}. At this point, the upper comparator 1 changes to a HIGH state.



Output of Comparator 2 Remains LOW **Output of Comparator 1 Changes to HIGH**

Figure 7 – Output Comparator 1 and 2 When V_{IN} Reaches 2/3 V_{CC}

8. Since the input R is HIGH and input S is LOW, the output $\overline{Q}$ of the SR flip-flop goes to HIGH.

- **Discharging:**
  9. The HIGH output from the SR flip-flop turns on the discharge transistor which creates a discharge path for C1 through R2.

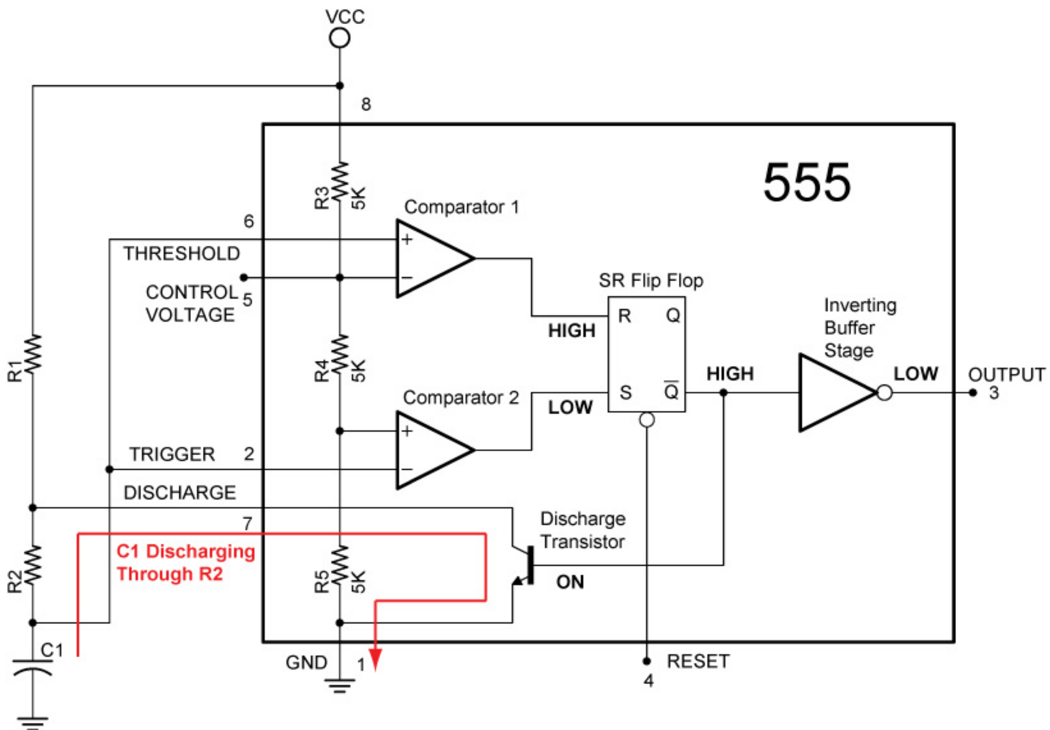
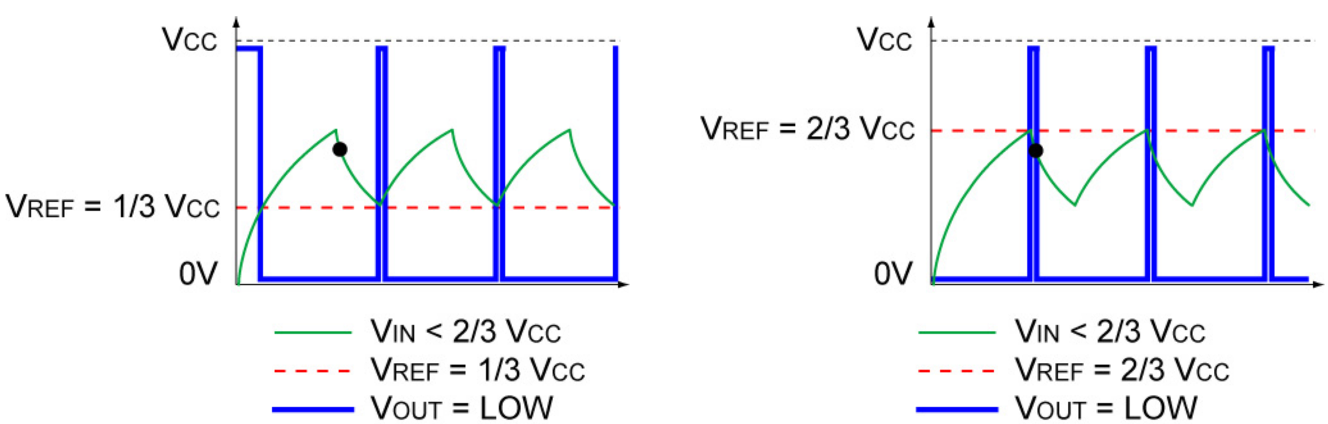


Figure 8 – C1 Discharging Through R2

10. The discharge of C1 causes the output of the upper comparator 1 to change to LOW.

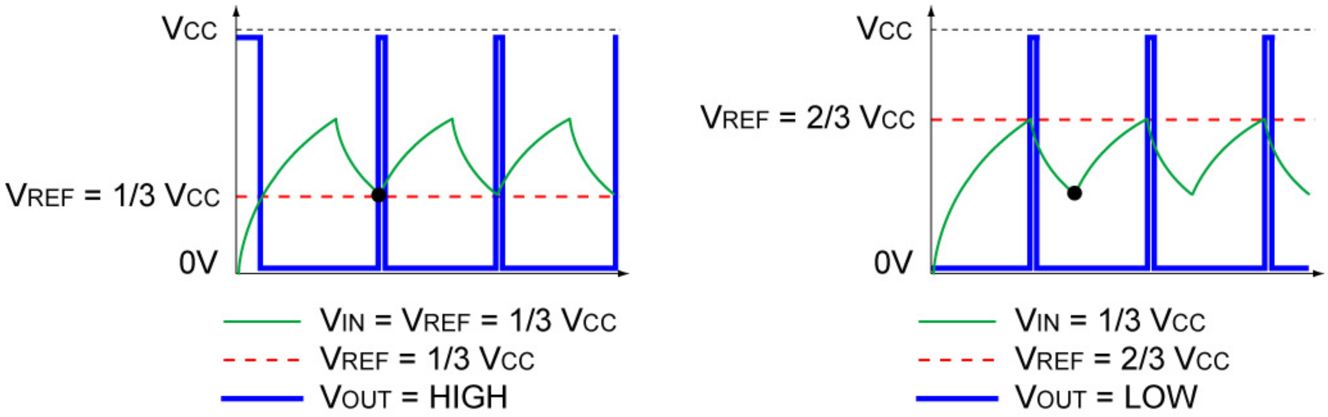


Output of Comparator 2 Remains LOW **Output of Comparator 1 Changes to LOW**

Figure 9 – Output Comparator 1 and 2 When $V_{IN} < 2/3\ V_{CC}$

11. The output $\overline{Q}$ of the SR flip-flop does not change (S=0 & R=0), thus remaining in a HIGH state.

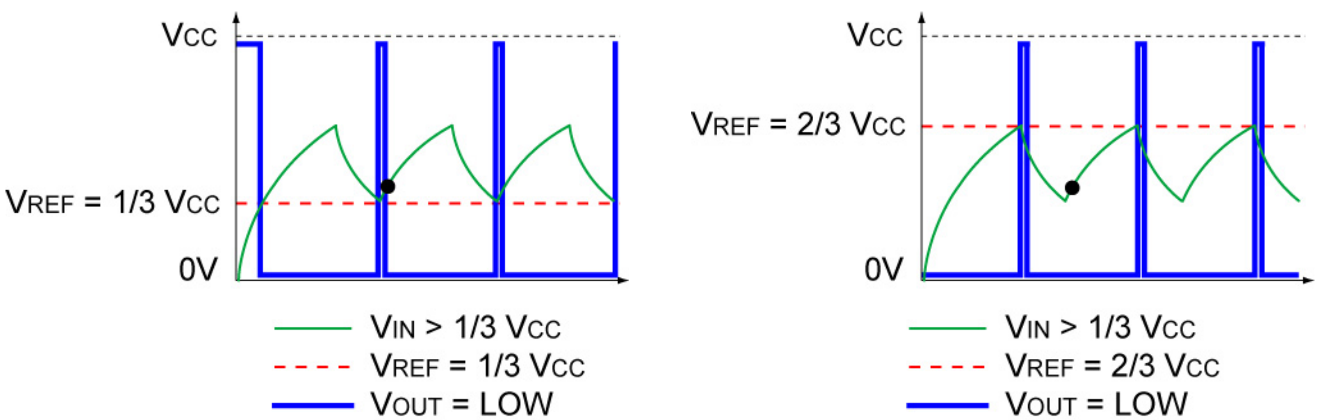
12. When C1 discharges to 1/3 V_{CC}, the lower comparator 2 output changes to HIGH causing the output $\overline{Q}$ of the RS flip-flop to go LOW (S is HIGH and R is LOW). The LOW output $\overline{Q}$ from the SR flip-flop turns off the discharge transistor and C1 begins to recharge.



Output of Comparator 2 Changes to HIGH **Output of Comparator 1 Remains LOW**

Figure 10 – Output Comparator 1 and 2 When V_{IN} Returns to 1/3 V_{CC}

13. The output of lower comparator 2 then changes to a LOW state, but the RE flip-flop remains LOW continuing to charge the capacitor C1. The capacitor continues the new recharge cycle.



Output of Comparator 2 Changes to LOW **Output of Comparator 1 Remains LOW**

Figure 11 – Output Comparator 1 and 2 When V_{IN} > 1/3 V_{CC}

14. The 555 timer repeats the charge/discharge cycle between 1/3 V_{CC} and 2/3 V_{CC} producing an output periodic square wave (Figure 12).

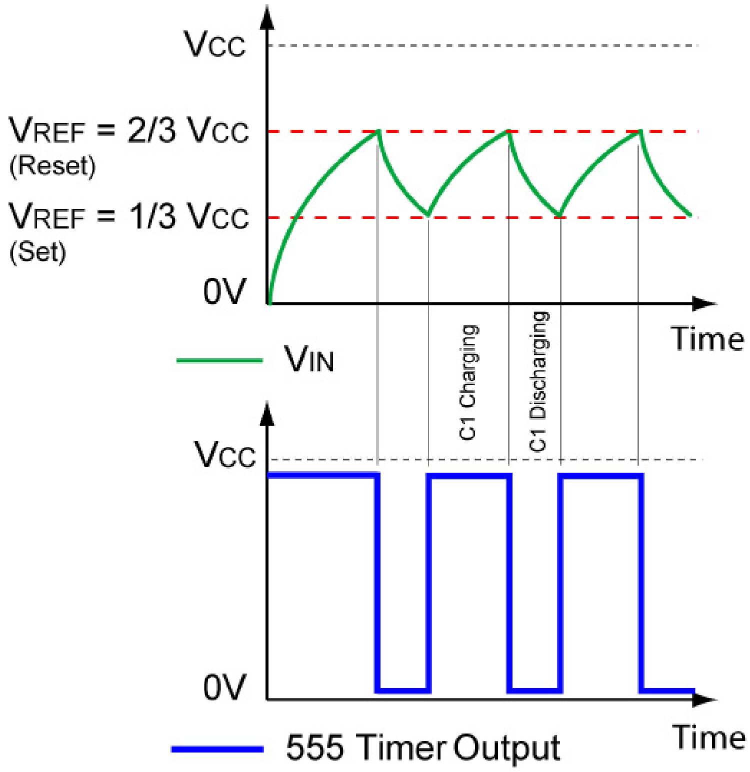


Figure 12 – Relationship between V_{IN} and the Output of the 555 Timer

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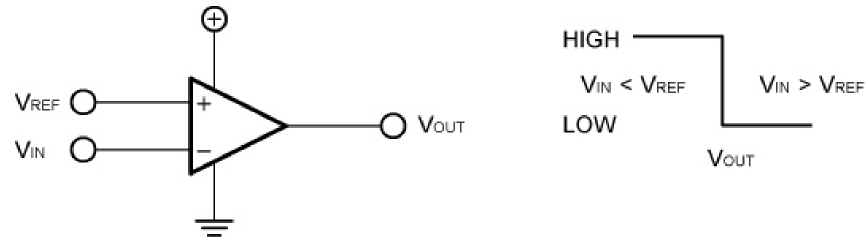
Review Basic Comparator Operations:

- Inverting Operation: When V_{IN} exceeds V_{REF}, the output V_{OUT} goes from HIGH to LOW.



The inverting operation can be represented in another graphical form:

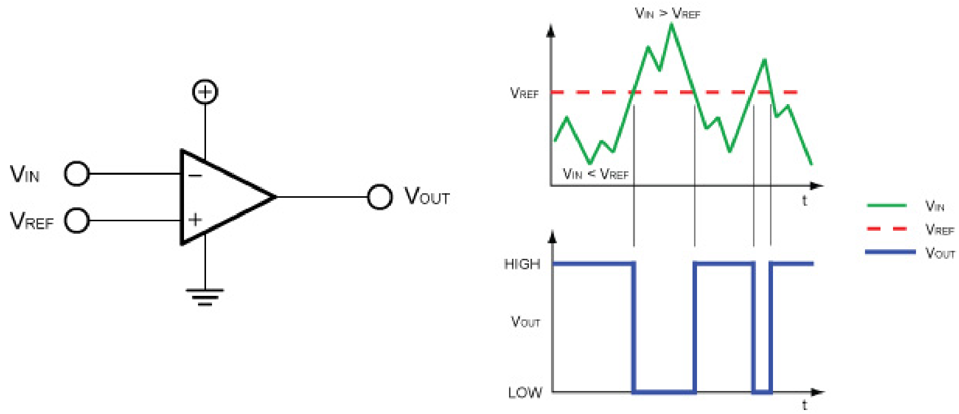
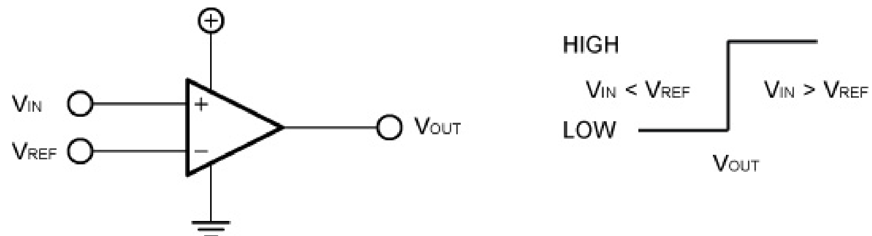


Figure 13 – Inverting Comparator Operation

- Non-inverting Operation: When V_{IN} exceeds V_{REF}, the output V_{OUT} goes from LOW to HIGH.



The non- inverting operation can be represented in another graph:

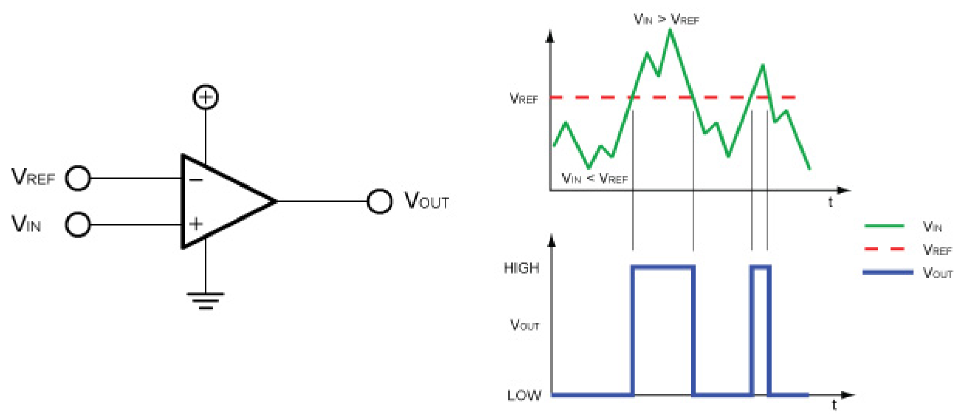


Figure 14 – Non-inverting Comparator Operation

Output Pulses and Formulas for Astable Operation:

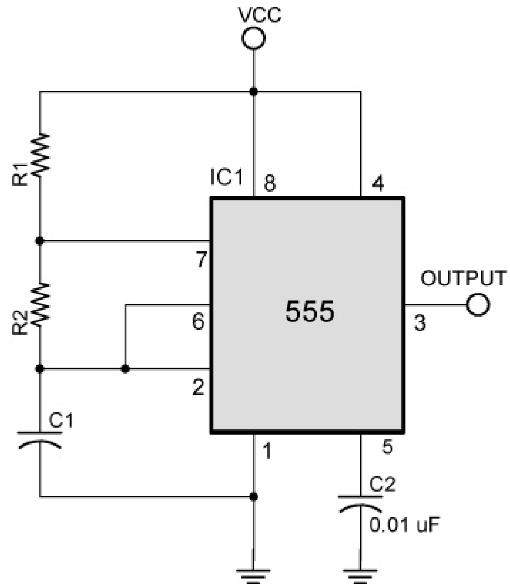


Figure 15: Astable Operation Circuit (Duty Cycle > 50%)

- Output Waveform from Astable 555 Timer Circuit in Figure 15:

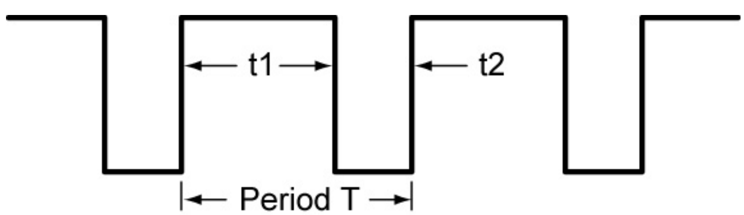


Figure 16 – 555 Timer Output Pulses for Astable Operation (Duty Cycle > 50%)

- Formulas:

$$t1 = 0.693(R1 + R2)*C1$$

$$t2 = 0.693(R2)*C1$$

$$f = 1 / T$$
$$f = 1/ (t1 + t2)$$
$$f = 1 / (0.693(R1 + R2)*C1 + 0.693R2*C1)$$
$$f = 1 / 0.693(R1*C1 + R2*C1 + R2*C1)$$
$$f = 1.44 / (R1 + 2R2)*C1$$

$$\text{Duty Cycle} = ((R1 + R2) / (R1 + 2R2)) * 100\%$$

Where:

t1 = the time the pulse is HIGH (the charge time) in sec
t2 = the time the waveform is LOW (the discharge time) in sec
R1 = resistance of R1 in Ω
R2 = resistance of R2 in Ω
C1 = capacitance of C1 in Farads
f = frequency in Hertz

- 555 Astable (Oscillator) Mode Chart:

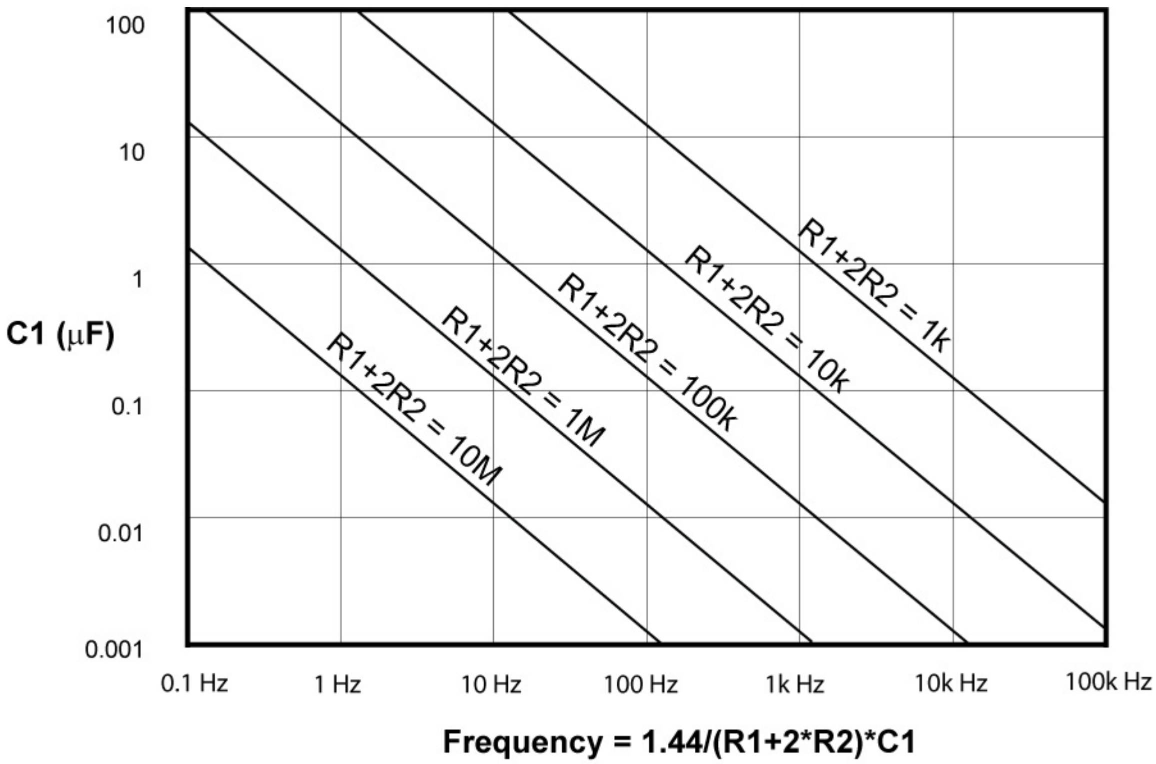


Figure 17 – 555 Timer Astable Frequency vs R1, R2, & C1 Graph

- A 555 Timer - Frequency and Duty Calculator is available on-line at: http://ourworld.compuserve.com/homepages/Bill_Bowden/555.htm
- Notes about the 555 Timer:
  - The supply voltage is +5 to +15V.
  - Output voltages at HIGH and LOW: When the 555 timer output is in the HIGH state, the output voltage is less than V_{CC} and when it is in the LOW state, the voltage is greater than 0 V. See output voltage HIGH and LOW in the electrical characteristics chart in the datasheet.
  - Range of Resistor Values:
    - For V_{CC} = 15V, the maximum value of R1 + R2 = 20 MΩ
    - For V_{CC} = 5V, the maximum value of R1 + R2 = 6.7 MΩ
  - Datasheets:
    - http://www.national.com/ds/LM/LM555.pdf
    - http://www.fairchildsemi.com/ds/LM/LM555.pdf
- Perform 555 Timers – Astable Operation LAB 1 – Design Astable Mode Oscillator for Middle C (262 Hz)

- **Circuit Limitations:** The circuit in Figure 15 has one inherent problem; it will not generate a square waveform with a duty cycle below 0.5 or 50%. The duty cycle is ratio of the pulse width (t1) to the period (T).

  Duty Cycle = t1 / T

  Duty Cycle = t1 / (t1 + t2)

  Duty Cycle (in %) = (t1 / T) * 100%

  Where:

  t1 = pulse width
  T = period

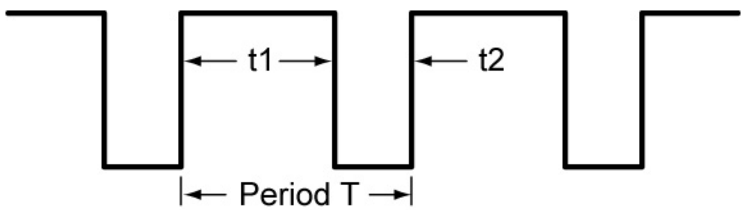
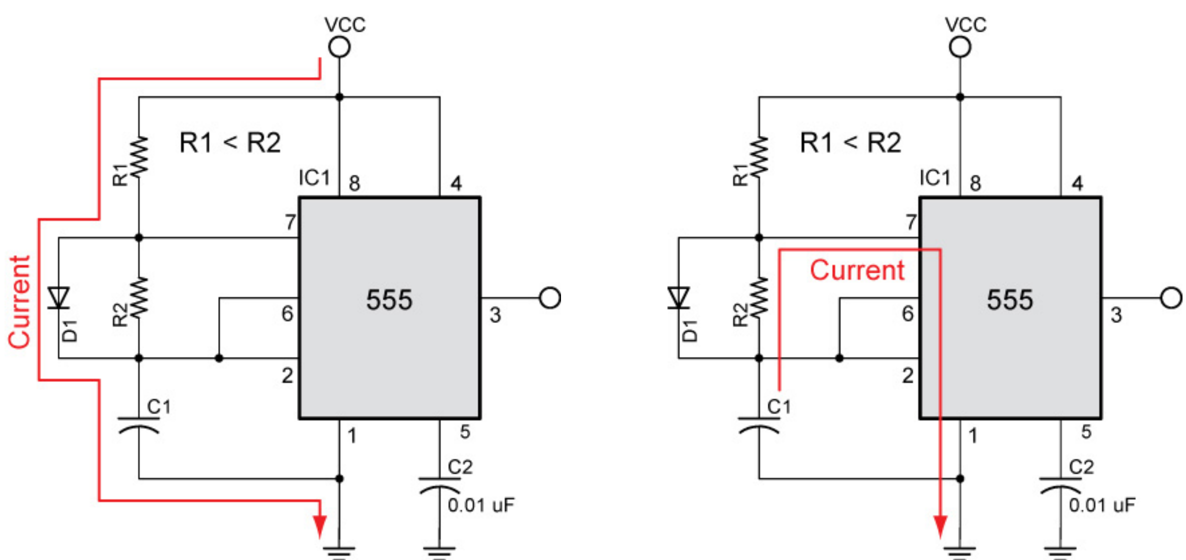


Figure 18 – Duty Cycle Terms

In our case, The 555 timer output is HIGH when the capacitor is charging through R1 and R2; it is LOW when discharging through R2. For the duty cycle to be below 50%, $Time_{HIGH} < Time_{LOW}$ (t1 < t2), which requires (R1 + R2)*C1< R2*C1 or R1 + R2 < R2. Since resistors values are always greater than zero (R1 and R2 > 0), R1 + R2 is never less than R2 and the duty cycle is always greater than 0.5 or 50%. To generate a duty cycle less than 50%, a diode is added to the circuit to bypass R2 during the charging process and the value of R1 is chosen to be less than R2 (R1 < R2). See the schematic in Figure 19.



C1 Charging Through R1 Only - Current Bypasses R2 Through D1

C1 Discharging Through R2

Figure 19 – 555 Timer Generates Output Pulses with Duty Cycle < 50%

With the diode in place and R1 < R2, the 555 output waveform has changed:

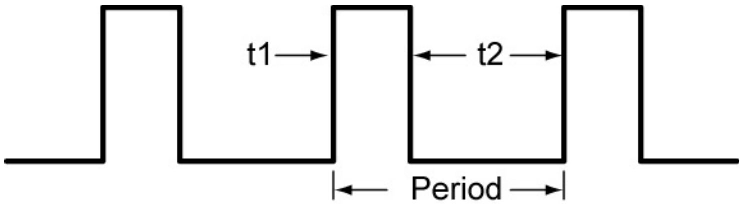


Figure 20 – 555 Timer Output Pulses for Astable Operation (Duty Cycle < 50%)

t1 = 0.693(R1)*C1

t2 = 0.693(R2)*C1

f = 1 / Period
f = 1/ (t1 + t2)
f = 1 / (0.693R1*C1 + 0.693R2*C1)
f = 1.44 / (R1 + R2)*C1

Duty Cycle = (R1 / (R1 + R2)) * 100%

Where:

t1 = the time the pulse is HIGH (the charge time) in sec
t2 = the time the waveform is LOW (the discharge time) in sec
R1 = resistance of R1 in Ω
R2 = resistance of R2 in Ω
C1 = capacitance of C1 in Farads
f = frequency in Hertz

- Perform 555 Timers – Astable Operation LAB 2 – Design a 555 Timer Circuit to Control a Hobby Servo Motor.

- **Robotic Applications:**
  - Can be used to generate pulses for ultra-sonic ranging systems.
  - Create pulse-width modulation signals (PWM).
  - Provide control signal to a hobby servo motor.

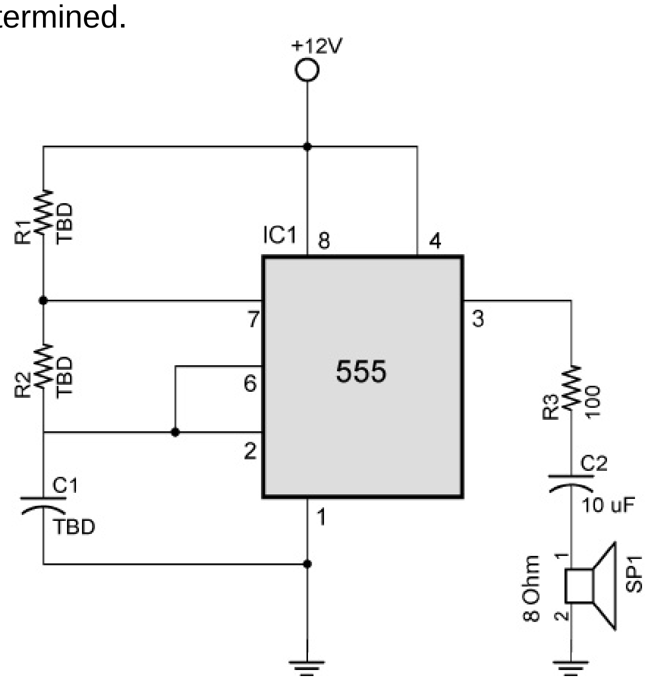
Cornerstone Electronics Technology and Robotics II
555 Timer LAB 1 – Design Astable Mode Oscillator for Middle C (262 Hz)

- **Purpose:** The purpose of this lab is for the student to design an oscillator that generates a tone at 262 Hz, the frequency of middle C.

- **Apparatus and Materials:**

  - 1 - Breadboard or Analog/Digital Trainer
  - 1 – 555 Timer IC
  - 1 – 100 Ohm Resistor
  - 2 – Resistors, value to be determined
  - 1 – Capacitor, value to be determined
  - 1 – 10 μF Capacitor
  - 1 – 8 Ohm Speaker

- **Procedure:**
  - Since we have one equation, (f = 1.44/ (R1 + 2R2) C1), and three unknowns, (R1, R2, & C1), we will either have to assume the value of two unknowns or use an aid to assist us in solving the equation. We will use an aid. Determine the approximate values of R1+2R2, and C1 from the 555 Timer Astable Frequency vs. R1, R2, & C1 Graph on the next page.
  - Using these approximate values, calculate the frequency from: f = 1.44/ (R1 + 2R2) C1
  - Now adjust the values of either R1 or R2 or both to close in the frequency of middle C, 262 Hz. Keep in mind the resistor and capacitor values available in the shop; they are listed on the following page.
  - Wire the circuit employing the resistors and capacitor values you have determined.



Astable Circuit to Generate Middle C Tone

- **555 Astable (Oscillator) Mode Chart:**

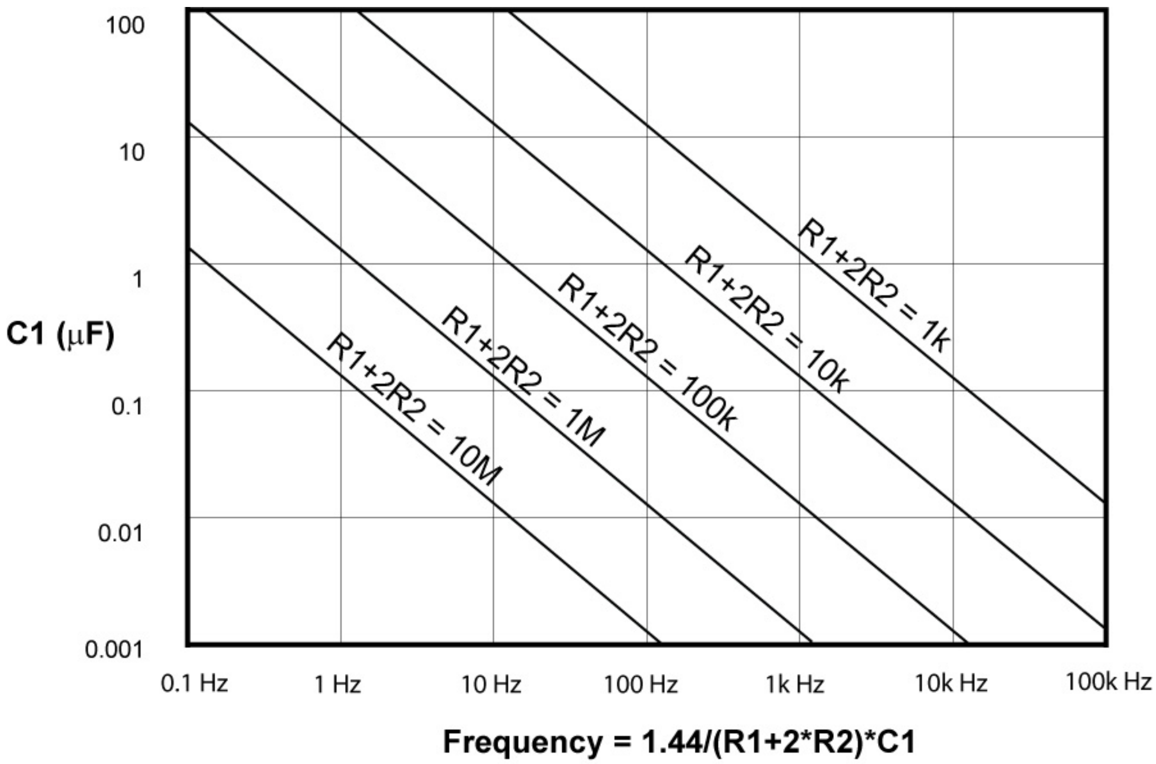


Figure 123456 – 555 Timer Astable Frequency vs. R1, R2, & C1 Graph

- Fixed resistor values available in the lab:
  - 10, 47, 150, 270, 330, 390, 470, 680, 1.2K, 1.5K, 2K, 2.2K, 2.7K, 3.3K, 5.1K, 5.6K, 15K, 20K, 22K, 33K, 47K, 470K, 1Meg, 10M ohm resistors
- Capacitor values available in the lab:
  - 22 pf, 0.001 uf, 0.01 uf, 0.022 uf, 0.033 uf, 0.047 uf, 0.1 uf, 0.47 uf, 1uf, 2.2 uf, 3.3 uf, 4.7uf, 10uf, 22 uf, 47 uf, 100uf, 220uf, 470uf, 1000uf, 2200uf, and 3300 uf

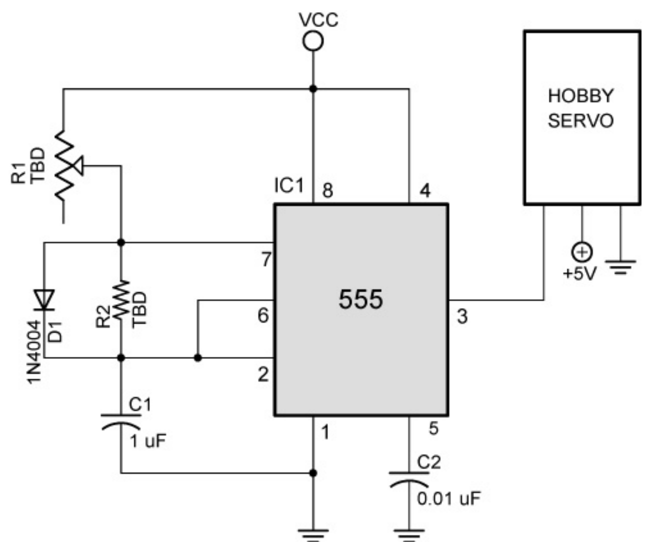
555 Timer LAB 2 – Design a 555 Timer Circuit to Control a Hobby Servo Motor

- **Purpose:** The purpose of this lab is for the student to design a 555 timer circuit that has a robotic application and also has a duty cycle less than 50%.

- **Apparatus and Materials:**

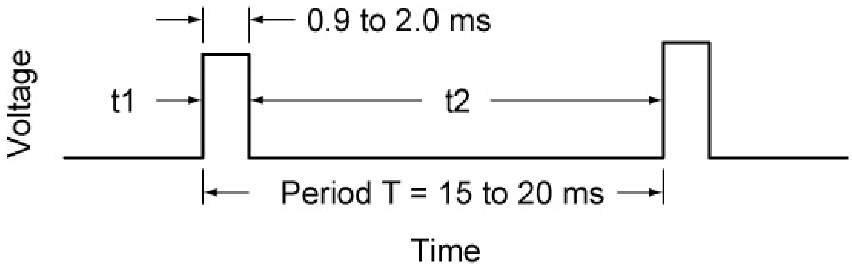
  - 1 – Breadboard or Analog/Digital Trainer
  - 1 – 555 Timer IC
  - 1– Potentiometer, value to be determined
  - 1 – Resistors, value to be determined
  - 1 – 1μF Capacitor
  - 1 – Hobby Servo Motor

- **Procedure:**



  - Assume C1 is 1μF.
  - Continued on the next page.

- A hobby servo requires a series of pulses 0.9 – 2.0 ms long with each pulse cycle having a period of approximately 20 ms. See the diagram below.



Hobby Servo Pulse Waveform Showing Pulse Width and Period T

- Solve for R1:
  - From the pulse waveform above, the pulse to a servo ranges from 0.9 to 2.0 ms. Knowing C1 (1μF) and assuming a pulse ($t1_{2.0}$) of 2.0 ms, solve for $R1_{2.0}$. Record your results.

    Remember, t1 = 0.693(R1)*C1

  - Choose a potentiometer R1 which has a maximum value slightly greater than $R1_{2.0}$. Record your results.
  - Now solve for $R1_{0.9}$ assuming $t1_{0.9}$ = 0.9 ms. Record your results.
  - The servo will only work properly when the potentiometer is within the range of resistances $R1_{0.9}$ to $R1_{2.0}$. You can tell the servo is responding properly when it locks into a position and resists rotation when you try to turn it.
- Solve for R2:
  - Assume a period of 20 ms.
  - Subtract the pulse time of 2.0 ms from the period to determine the time t2.
  - Now solve for R2.

    t2 = 0.693(R2)*C1

  - Record your results.
  - Choose a resistor or a combination of resistors that approximate the calculated value of R2. Record your results.
- Test the servo using the 555 timer as the servo controller

o **Results:**

- $R1_{2.0}$, $R1_{0.9}$ and R2:

	Calculated Value	Value Used
$R1_{2.0}$		
$R1_{0.9}$		
R2		