ENGR 210 Lab 10
RC Oscillators and Measurements

Purpose

In a previous lab you measured the exponential response of RC circuits. Typically, the exponential time response of a circuit becomes important when you are trying to do something very fast (like changing digital signals on a computer bus) or when you are trying to time something. Timing is extremely useful to anyone working with sensors, real-time control, or data acquisition. Therefore, this lab is devoted to a special type of integrated circuit called a timer, which uses the exponential response of a simple RC circuit to time events, create pulses of known duration, and even convert information into pulses which can be easily counted by a computer.

Background

The most popular timer or waveform-generator IC is the 555 (and its successors). It is also an easily misunderstood chip. A simple equivalent circuit of the 555 is shown in
Figure **1**. A resistor divider network produces reference voltages of $1/3V_{CC}$ and $2/3V_{CC}$ for the op amps — V_{CC} is the voltage used to power the chip, typically 5 volts or more. The two op amps function as comparators causing the output to change whenever the input voltage goes above or below their reference input. For example, whenever the TRIGGER* input is below $1/3V_{CC}$ the output of the 555 is high (near V_{CC}). The THRESHOLD works in exactly the opposite way; whenever the THRESHOLD input is above $2/3V_{CC}$ the output of the 555 will be low (approximately zero). There is also a separate transistor output called DISCHARGE which can be used as a separate switch to turn things on and off. By connecting these inputs and outputs in clever ways the 555 can be made to perform a very large number of electrical functions.
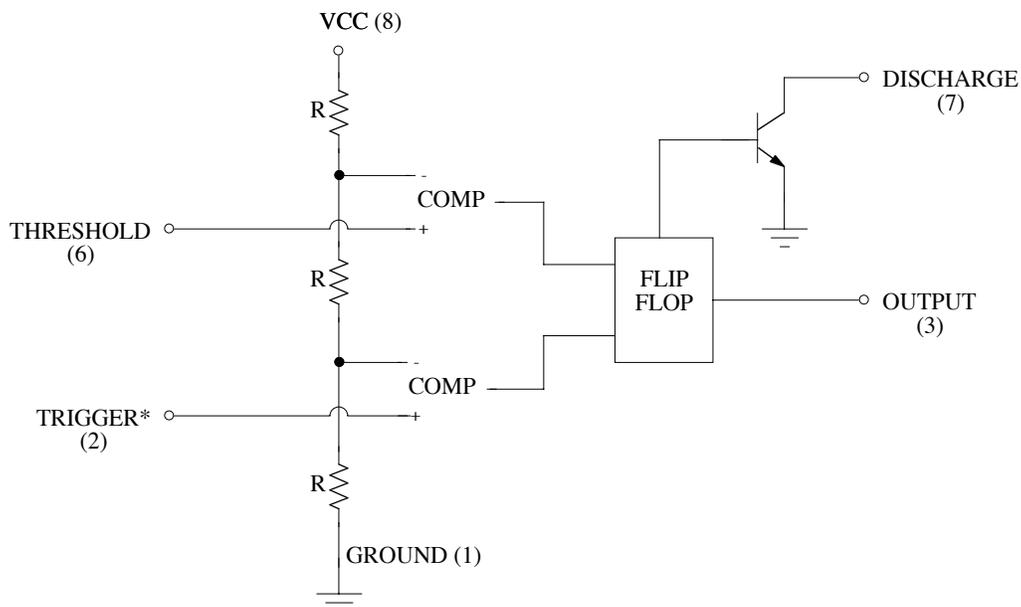

Figure 1. Simplified 555 schematic.

NOTE: The * in the TRIGGER* is a common digital logic notation for indicating that this is a low true logical signal. When you see TRIGGER* you read it and say it as NOT TRIGGER. We will learn about digital logic later; however, a normal digital logic signal is "true" when it is high or near 5 volts, and "false" when it is low, or near zero volts. This is called a high true signal since the voltage is high when the signal is true. The * simply indicates that the logic signals are inverted, or low true — the signal is "true" when the voltage is near zero, and "false" when the voltage is near 5 volts.

The easiest way to understand the workings of the 555 is to look at an example. Figure 2 shows the 555 connected to operate as an oscillator. When the power is first turned on, the capacitor is initially discharged; so the 555 TRIGGER* input is low (near zero) which makes the OUTPUT HIGH, the DISCHARGE transistor is open, and the capacitor charges toward 10 volts (the power supply voltage) through $R_A + R_B$. When the capacitor voltage reaches about $2/3*V_{CC}$, the op amp connected to the THRESHOLD input causes the OUTPUT to go to zero. The DISCHARGE switch also turns on and shorts C to ground through R_B. This causes the capacitor voltage to decrease to zero. However, as soon as C's voltage drops below $1/3*V_{CC}$ the op amp connected to the TRIGGER* input senses this. The op amp output changes which causes the 555's OUTPUT to go high and opens the DISCHARGE pin causing C to charge up again. The basic operation of this circuit is cyclic, with C's voltage going back and forth between $1/3*V_{CC}$ and $2/3*V_{CC}$, with a period given by $T = 0.693(R_A+2R_B)C$. This formula is an approximate one supplied by the manufacturer on data sheets for the 555.
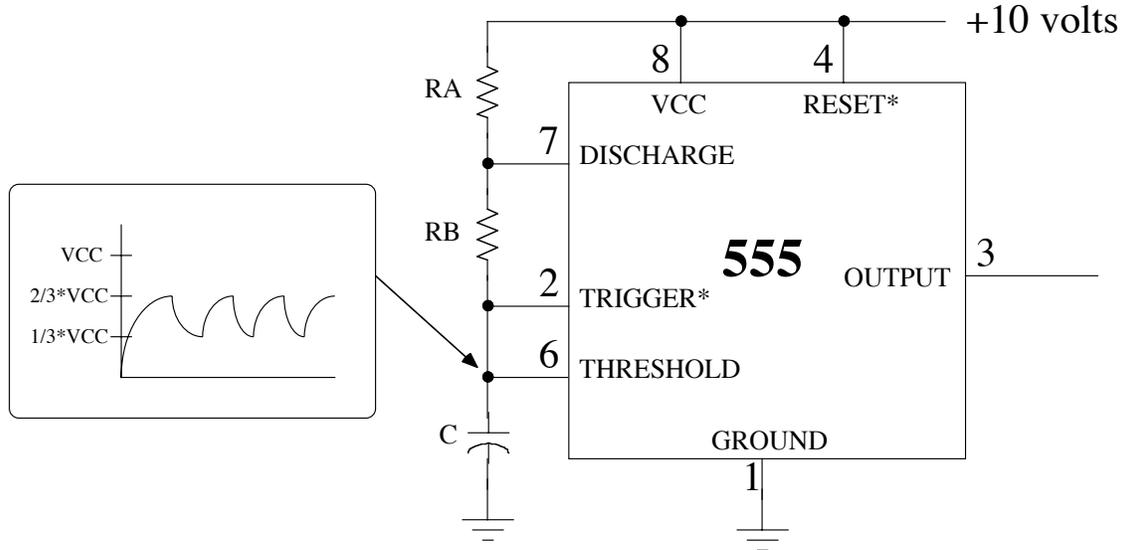
Figure 2. The 555 connected as an oscillator.

A circuit that produces a repetitive output like that shown in Figure 2 is called an oscillator. The 555 makes a pretty good oscillator. The 555 can also be used to generate single pulses of arbitrary width. This type of circuit is called a monostable or one shot and is extremely useful to "clean up" noisy pulses. Because the 555 integrated circuit contains comparators, gates, and flip-flops people have found many non-timer uses for the 555 and it has become a game in the

electronics industry to try to think of new uses for the 555. Incidentally, a 555 is used as a timer in many of the deep-fat fryers you see in fast food stores.

A caution about the 555: Whenever you discharge a capacitor you generate large instantaneous currents, which can interfere with other integrated circuits. Whenever you are using the 555 with any other integrated circuits you should put a capacitor (the value is not critical and can be from $0.1\mu f$ to $2.2~\mu f$) from the power supply lead to the ground lead. Good practice is to put this capacitor as close to the chip as possible. If you ever encounter strange outputs from the 555 or oscillations in other integrated circuits used in a circuit with the 555 you probably forgot to bypass the 555 or the bypass capacitor should be larger. You should not need a bypass capacitor in the simple 555 circuits you will build in this lab.

Lab Procedure

1: Locate a data sheet for the 555 integrated circuit

Locate and find a data sheet for the 555 integrated circuit timer chip. Hint: you can use the chip specific search engines on the ENGR 210 home page — check under "Tools"--> "Chip Selector". A further hint: These timer chips were originally known as the NE555. Any other letters such as LM and LMC preceding the 555 usually indicates an improved version of the 555. Attach a **one-page** copy of the 555 **pinout** from this data sheet to your lab report — *points will be taken off for multipage submissions.*
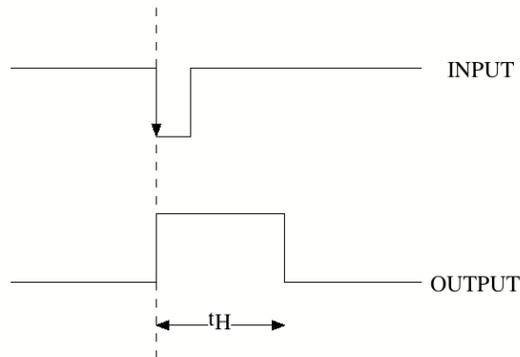
2: 555 One Shot

A very useful circuit is a one-shot, also called a monostable. Basically a one-shot produces a longer output pulse in response to a short input pulse. These circuits have important applications in digital circuits where they can provide signal delays and can "stretch" very short pulses into longer pulses to operate computer logic more reliably. These circuits also are used in digital communications, biomedical engineering, and any other application where you need to clean up a digital signal in the presence of noise. A typical one-shot circuit using the 555 is shown in Figure 3.
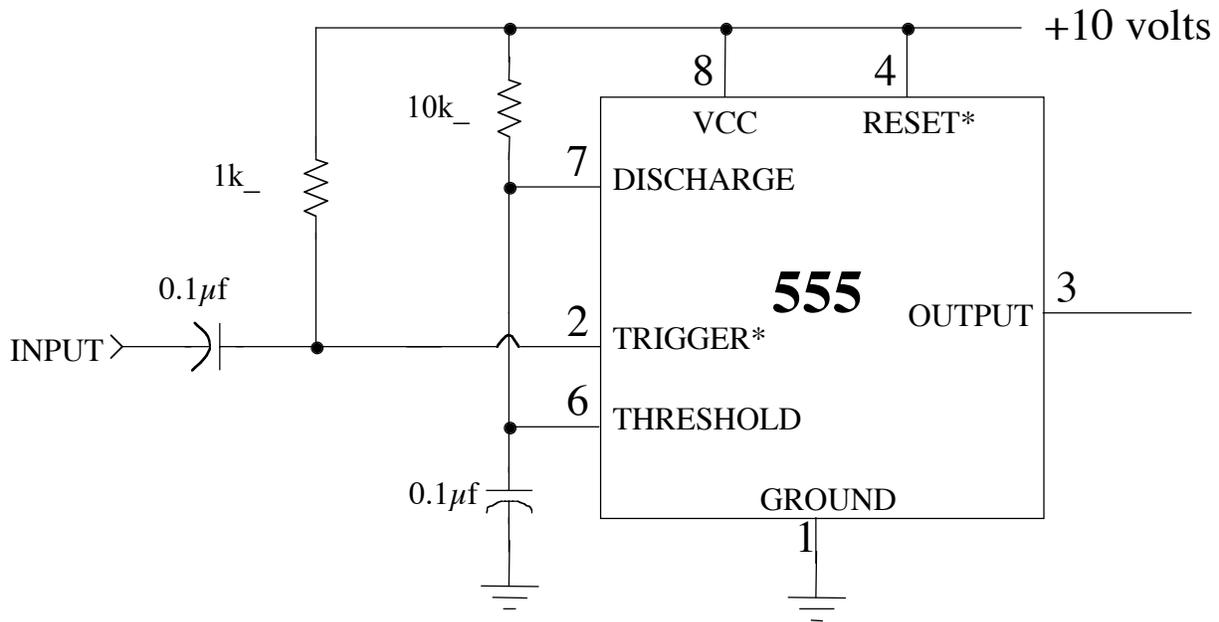
Figure 3. 555 one-shot

The TRIGGER pulse must be shorter than the desired t_H . A negative going (or falling) input pulse will cause the 555 output to go high as shown in Figure 4. As long as the input pulse is low (for at least 20 nanoseconds), the output is a positive going pulse which will remain high (near the supply voltage) for a time t_H specified by the manufacturer to be approximately given by

$$t_H = 1.1 \, R_A C \qquad\qquad\qquad (2)$$

Figure 4. 555 one-shot waveforms

(a)   Construct the 555 monostable shown in Figure 3. Note that you only need to make a few small changes from your previous circuit. Connect the trigger input (Pin 2) to the H-P function generator. **BE SURE THAT THE FUNCTION GENERATOR IS IN HIGH Z MODE.** Adjust the generator output for a 4% duty cycle (a very narrow pulse) at about 100 Hz. See the note below in the box just before the next section for how to do this!

(b)   Connect the output from the function generator to Channel 1 of your scope. Connect monostable output from pin 3 to Channel 2. Vary the duty cycle of the H-P function generator. The monostable should be producing pulses which have a constant width (as determined by the R_A and C in your monostable circuit) at the frequency determined by the function generator. Record your oscilloscope display using Benchlink.

NOTE: There is a special note on the H-P Web site about adjusting the 33120A to produce very low duty cycle output pulses. The procedure appropriate for this part of the lab is:
1. Power up the H-P 33120A
2. Set the frequency to 1 kHz
3. Set the amplitude to 10 Vp-p
4. Select square wave output
5. Set the duty cycle to 60%
6. Select Burst Modulation (this is above one of the front panel buttons)
7. This should produce a 400 μs negative going pulse similar to that shown in Figure 4 at the 555's TRIGGER* input.

3: 555 IC Relaxation Oscillator

The 555 and similar chips have made the design of relatively complex circuits such as oscillators relatively easy. An RC circuit connected to the 555 as shown in Figure 5 alternately charges and discharges.   The frequency of these changes (the oscillation frequency) is claimed by the manufacturer to be approximately given by

$$f_{osc} = 1 / (0.7 \, [R_A + 2R_B]C) \tag{1}$$

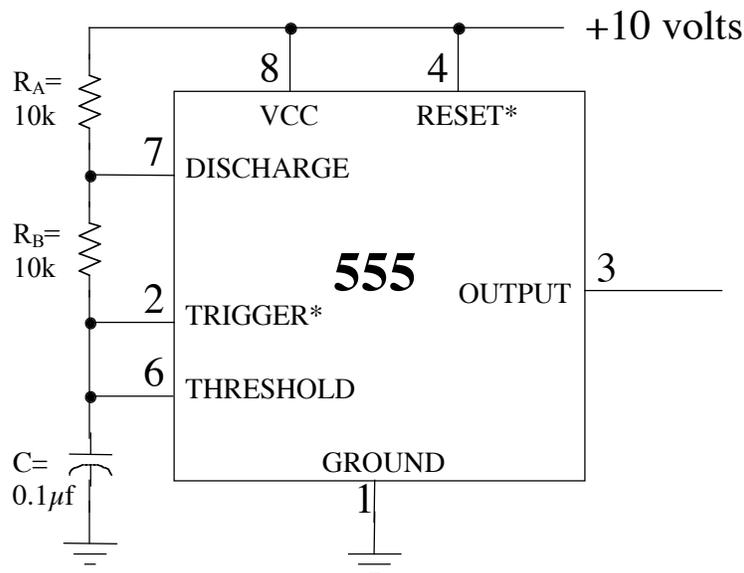

Figure 5. 555 relaxation (astable) oscillator

(a)   Construct the 555 relaxation oscillator shown in Figure 5.
(b)   Look at the output waveform from Pin 3 with Channel 1 of your oscilloscope. Simultaneously look at the capacitor waveform (at Pin 6) with Channel 2 of your
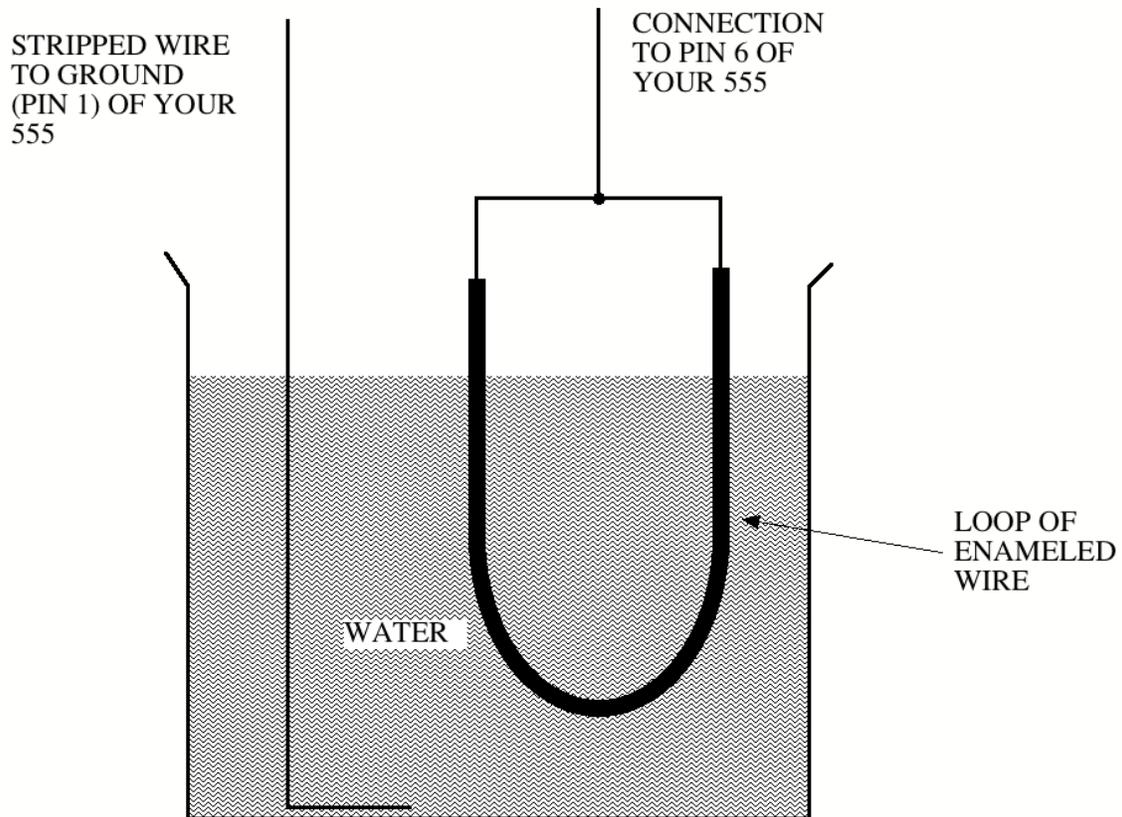
oscilloscope. Be sure to use scope probes for these measurements. With both the output and capacitor waveforms showing on your oscilloscope display, record your waveforms using Benchlink Scope.

(c)   Replace R_B with a short circuit (a wire). Make sure you see both the output waveform from pin 3 and the threshold waveform from pin 6 on your oscilloscope display. Record these voltage waveforms using Benchlink Scope.

4: 555 Water Level Sensor

This is a complex application of the 555. We are going to use the 555 to construct a sensor that measures the level of water in a beaker.

(a)   Construct the circuit from Figure 5, replacing R_A with a 22kΩ resistor and replacing R_B with a short circuit (a wire).

(b)   You will now replace C with a homemade capacitor consisting of two connections to a beaker of water. One connection will connect the circuit ground to the water. This can be a simple wire with the end stripped bare. Bend the wire near the end to get an L as shown in Figure 6 (The L shape helps hold the wire in the water and gives a better signal). Place the bent, bare end in the water. The other lead will be made from 10-20 inches of enameled wire — this is thin wire covered with a thin insulating varnish (paint). You may have to sand or scrape the ends of the wire to get a good electrical connection to your circuit. This is not as easy as it sounds! Be sure that no bare metal from this second wire comes in contact with the water. Fold this wire into a loop and place it into a beaker partially filled with water. Connect the two bare ends of this wire together and to your circuit as shown in figure 6

(c)   Turn on the power supply. Display the input and output waveforms of your circuit on the oscilloscope. Record these waveforms using Benchlink Scope.

(d)   Vary the water level by adding water to the beaker. Measure and record the frequency of the output signal as a function of the water level. You can estimate the water level by looking at the beaker, or even using a small ruler. Your measurements of the water level do not need to be very accurate as we are not interested in calibrating this sensor.

STRIPPED WIRE TO GROUND (PIN 1) OF YOUR 555

CONNECTION TO PIN 6 OF YOUR 555

LOOP OF ENAMELED WIRE

WATER

Figure 6. Home made capacitor for water level sensor

Producing a signal whose properties vary as a function of some sensed quantity (in this case water level) is a very common way for a modern sensor that interfaces to a computer to work.

WHEN DISASSEMBLING THE CIRCUIT, BE SURE TO CAREFULLY REMOVE THE 555 TIMER CHIP AND PLACE IT BACK IN THE BIN WHERE YOU FOUND IT.

DATA AND REPORT SHEET FOR LAB 10

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Lab Group: _____

Data Table 1. 555 output as a function of water level.

water level	Frequency of 555 output waveform

Make sure you have collected the following oscilloscope displays before leaving the lab.

Part 2(b). Oscilloscope display of 555 one-shot output.

Part 3(b). Oscilloscope display of 555 oscillator output. R_B=10kΩ

Part 3(c). Oscilloscope display of 555 oscillator output. R_B=short

Part 4(c). Oscilloscope display of water level sensor output.

Attach the 555 data sheet and your four oscilloscope displays to this report. Label each one.

For Part 1:
1. Where (what URL) did you find your data sheets?

For Part 2:
1. Is the width of the pulses correctly predicted by Equation (2) as claimed by the manufacturer? If not, explain why not.

2. What are the maximum and minimum voltages of the output waveform?

3. Will these vary of you change the input voltage (the voltage from the signal generator)? Why or why not?

For Part 3:
1. For your measured output of the oscillator is the frequency correctly predicted by Equation (1) as claimed by the manufacturer? If not, explain why not.

2. What are the maximum and minimum voltages on the capacitor? Do these values make sense in terms of how the 555 is supposed to operate?

3. Give an explanation for what happened when you shorted R_B in step 4.

4. What would happen if you replaced R_A with a thermistor, a resistor whose value is directly proportional to temperature? Qualitatively describe the behavior of this circuit as a function of temperature.

For Part 4:
1. What is the range over which frequency of your output waveform from the 555 changed as you varied the water level?