ENGR 210 Lab 7
RC Oscillators and Measurements

Motivation
We could have had you do a lab in which you measured the exponential response of RC and RL circuits but we thought that would be pretty boring and simply repeat what you have been doing in class. Typically, the exponential time response of a circuit becomes important when you are trying to do something very fast (like a digital signal on a computer bus) or when you are trying to time something. Since timing is extremely useful to anyone working with sensors, real-time control, or data acquisition 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 sensor information into pulses which can be easily counted by a computer.

Background: the classic timer chip: the 555
The most popular timer or waveform-generator IC is the 555 (and its successors). It is also an easily misunderstood chip. The equivalent circuit of the 555 is shown in Figure 1. Some of the symbols are digital and you really have not seen them before (unless you are taking ECES 281), so you probably won't become a 555 expert for a while yet. But the operation of the 555 chip is simple enough: The OUTPUT (pin 3) goes high (near $V_{CC,}$ typically 5 volts) when the 555 receives a TRIGGER* input, and it stays there until there is an input at the THRESHOLD input, at which time the OUTPUT goes low (near ground) and the DISCHARGE transistor (for the moment just think of the transistor as a switch) is turned on. The TRIGGER* input is activated by an input level below $1/3*V_{CC}$, and the THRESHOLD is activated by an input level above $2/3*V_{CC}$. Incidentally, the * in the TRIGGER* indicates 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 normal high true signal; the * 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. If this is still confusing, just look at the waveforms near pins 2 and 6 in Figure 1. They show, for example, that the TRIGGER* input operates when the voltage at pin 2 drops below $1/3*V_{CC}$.

The easiest way to understand the workings of the 555 is to look at an example. Figure 2 shows the 555 operating as an oscillator. When the power is turned on, the capacitor is initially discharged; so the 555 TRIGGER* input is true and causes the output to go HIGH, the discharge transistor Q_1 to switch off, and the capacitor to begin charging toward 10 volts through $R_A + R_B$. Figure 2 is poor but the power supply voltage is +10 volts. When the capacitor charges up to about $2/3*V_{CC}$, the THRESHOLD input is true, causing the output to go LOW and Q_1 to turn on, which shorts C to ground through R_B. The operation of this circuit is cyclic, with C's voltage going between $1/3*V_{CC}$ and $2/3*V_{CC}$, with a period $T = 0.693(R_A+2R_B)C$. This formula is an approximate one supplied by the manufacturer on data sheets for the 555. The output you generally use is the square wave output at pin 3 of the 555.

The 555 makes a pretty good oscillator, with stability approaching 1% — that means that the frequency does not change by more than 1%. It can run from a single positive supply of 4.5 to 16 volts with the exact value not being critical, maintaining good frequency stability with supply voltage variations. This happens because the chip switches at $1/3*V_{CC}$ and $2/3*V_{CC}$ and simply follow any fluctuations in V_{CC}. The 555 can also be used to generate single pulses of arbitrary width, this is called a monostable or one shot. This is extremely

useful to "clean up" noisy pulses. Because the chip 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 an analog-digital converter in many of the deep-fat fryers you see in fast food stores.
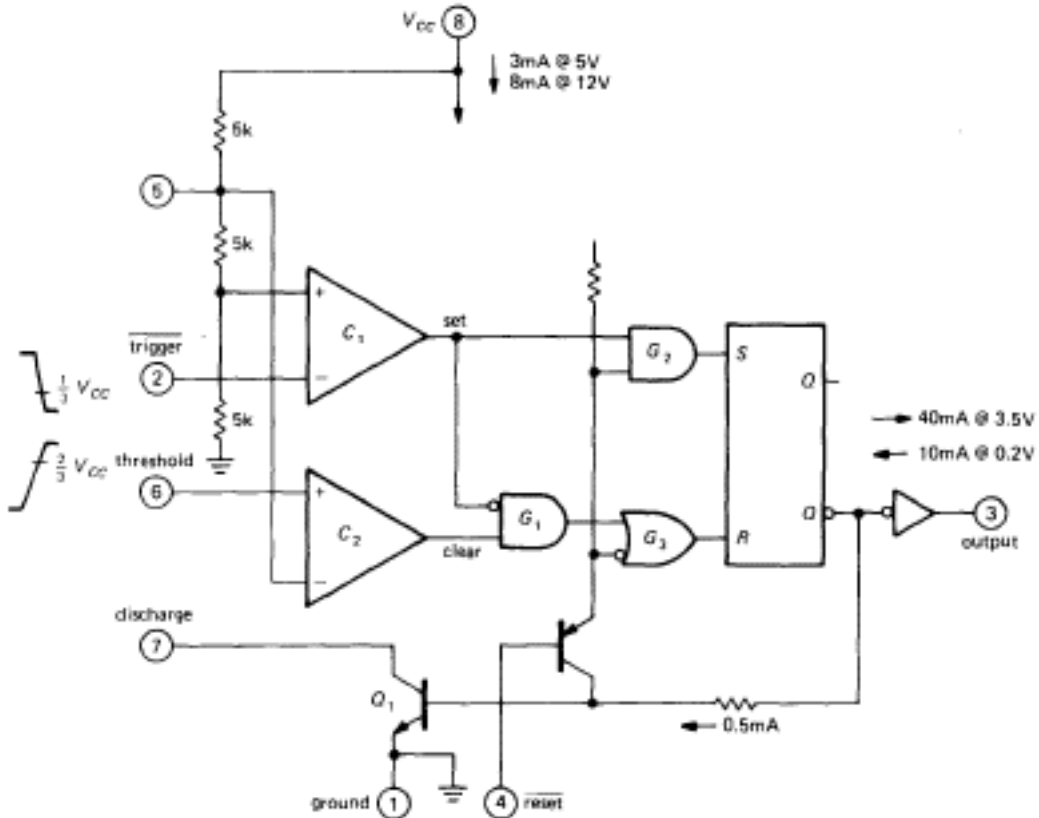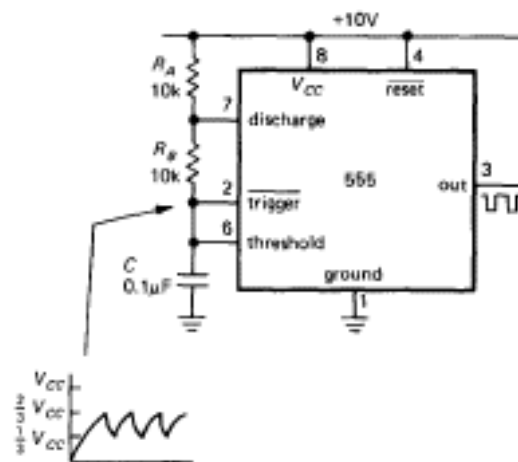

Figure 1. Simplified 555 schematic.

Figure 2. The 555 connected as an oscillator.

A caution about the 555: The 555, along with some other timer chips, generates a big (~150mA) supply-current glitch during each output transition; modern CMOS versions are better and do not generate current spikes that are as large. Be sure to use a hefty bypass capacitor near the chip. This means that if you are using it with any other integrated circuits you should put a capacitor from the power supply lead to the ground lead. Practice is to put this capacitor as close to the chip as possible. You can even buy integrated circuit sockets with a capacitor between power and ground built in. A good value of bypass capacitor is from 0.1μf to 2.2 μf. 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.

Part A: Locate a data sheet for the 555 and 556 integrated circuits

Locate and find a data sheet for both the 555 and 556 integrated circuit timer chips. 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 used to be known as the NE555 and NE556. Other letters preceding the three digit numbers such as LM and LMC are also possible. These other letters designate improved versions of the 555 made with CMOS. One such example is the 7555 which runs up to 500 kHz (versus 100 kHz for the 555). It also has a very high input impedances and larger output swings (a characteristic of CMOS). Attach copies of these data sheets to your lab report.

Part B: 555 IC Relaxation Oscillator

The 555 and similar chips have made the design of moderate-frequency oscillators easy. There is seldom any reason to design an oscillator from scratch. The RC circuit alternately charges and discharges and the output frequency of oscillation is claimed by the manufacturer to be approximately given by

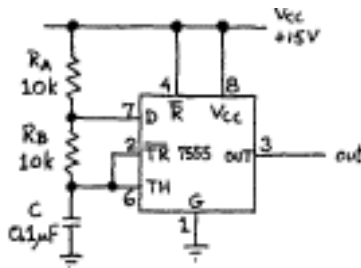$$f_{osc} = 1 /(0.7 [R_A + 2R_B]C) \qquad\qquad (1)$$

Figure 3. 555 astable oscillator

1. Construct the 555 relaxation oscillator shown in Figure 3. Use 10 volts instead of 15 volts.

2. Look at the output waveform from Pin 3 with an oscilloscope. Sketch your output in Data Table 1.

3. Now look at the waveform on the capacitor (at Pin 6) with your oscilloscope. Be sure to use scope probes for this measurement. Sketch this waveform in Data Table 2.

4. Now replace R_B with a short circuit (a wire). Sketch the output voltage in Data Table 3. Sketch the capacitor voltage in Data Table 4.

Part C: 555 One Shot

A one-shot is a device which, in response to a short trigger pulse, produces a longer 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 have important applications 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 4.
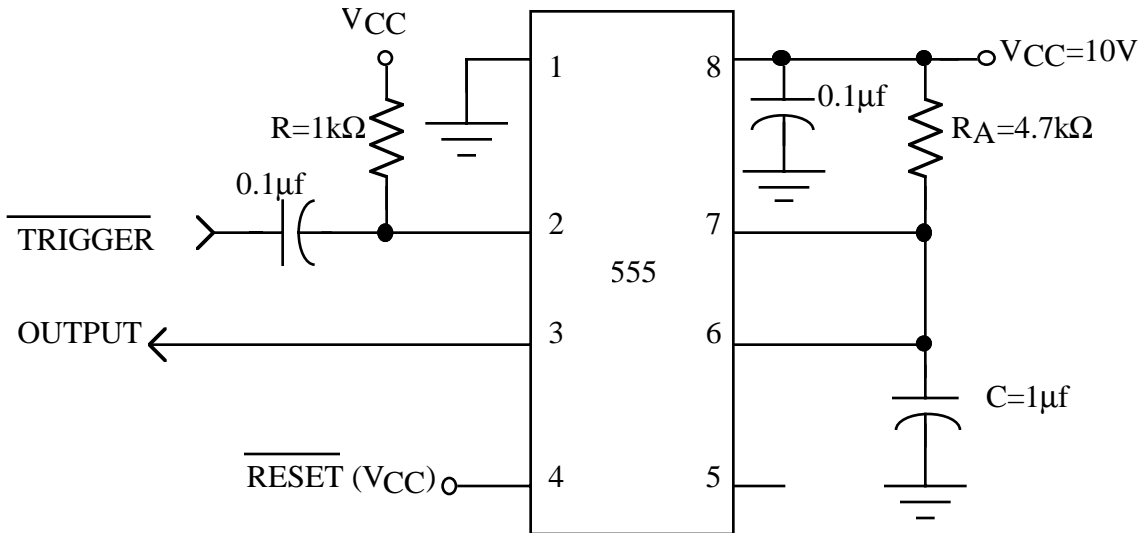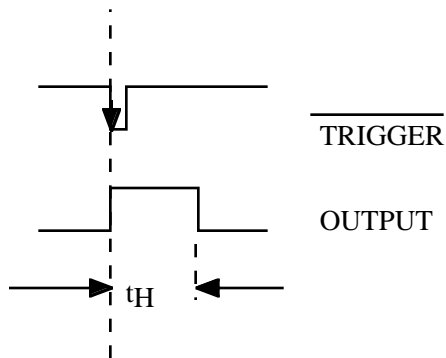

Figure 4.   555 monostable

Figure 5. 555 waveforms: input (upper), output lower

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 which is specified by the manufacturer to be approximately given by

$$t_H = 1.1 \, R_A C \tag{2}$$

There is also a RESET* input which can override the TRIGGER* and THRESHOLD inputs to the chip—we will not use this feature in this lab. The trigger pulse must be shorter than the desired t_H. The technique used in Figure 4 to trigger the 555 is described in the Phillips Semiconductor data sheets. The resistor R and the 0.1μf capacitor at the

TRIGGER* input act as a differentiator of the input input. These circuit values will differentiate the narrow negative pulse (described below) to produce a large negative going pulse (which will trigger the 555) and a slightly smaller positive going pulse (which will be ignored by the 555). These pulses respectively correspond to the negative going edge and the positive going edge of the function generator's output. The procedure for building and testing a 555 monostable is:

1. Construct the 555 monostable shown in Figure 4. Drive the trigger input (Pin 2) with the H-P function generator. Adjust the generator output for a 4% duty cycle (a very narrow pulse) at about 100 Hz. See the note below for how to do this!

2. Look at the output from the function generator on Channel 1 of your scope. Look at the output of the monostable on Channel 2. Vary the duty cycle of the H-P function generator. The monostable should be producing pulses which have a constant width (determined by the R_A and C in your monostable circuit) at the frequency determined by the function generator. Sketch your oscilloscope display in **Data Table 5**.

NOTE: There is a special note on the H-P Web site about adjusting the 33120A to produce very low duty cycle output pulses. This procedure appropriate for this part of the lab is:
1. Power up the H-P 33120A and **set the output to HIGH Z mode**. This is very important!
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 5 at the 555's TRIGGER* input.

Part D: 555/556 Water Level Sensor

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

1. Build the circuit of Figure 3. Replace R_A with a 22kΩ resistor. Replace R_B with a short circuit (a wire).
2. 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. The bare end must go in the water.
3. 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 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 7.
4. Turn on the power supply. Look at the output of your circuit using the oscilloscope.
5. 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 in Data Table 6. 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.

Producing a frequency which varies as a function of some sensed quantity (in this case water level) is a very common way for a modern sensor which interfaces to a computer to work. The computer simply counts the pulses as a function of time and does not need an analog-to-digital converter for that sensor. Now we are going to look at a much more complicated sensor which is designed to work with a DC voltmeter.

1. Build the circuit shown in Figure 7 using the component values from Table 1. This circuit can actually be built using two 555's; however, to make this simpler to build will use using the 556 which is two 555's in one package. The first timer in the 556 operates as an oscillator similar to what you built in Part B. The second 555 operates as a one shot similar to what you built in Part C. However, the second 555 is operated as a variable modulator changing the pulse width of the oscillator output in accordance with the level of the water in a beaker. Use the same homemade capacitor you used for the previous part for the water level sensor.
2. Connect the output from pin 9 of this circuit to your scope input. Also connect the DMM (set to measure DC volts) to the output from pin 9.
3. Place the capacitor sensor wires in the beaker. The beaker should be approximately 25% full initially. Turn on the circuit power.
4. Adjust the scope to get a good picture of the output waveform.
5. Vary the water level by adding a little bit of water. Record the width of your output pulses as measured by the oscilloscope and the DC voltage as measured by the DMM as a function of the water level. Sketch a typical oscilloscope display in Data Table 8.

NOTE: If the DC voltmeter reading is fluctuating too much to get a good reading you will need to add a filter to your circuit. The circuit diagram for a suitable filter is shown in Figure 6. The component values shown are just suggested values and you can substitute resistors and capacitors of different values over a wide range.

Component	Value
R1	47kΩ
R2	1kΩ
R3	1kΩ
R4	22kΩ
C1	0.001µf
C2	0.01µf
C3	0.001µf
C4	0.001µf
C5	constructed from enameled wire

Table 1. Component Values for the Circuit of Figure 7.

3.3kΩ

10μf
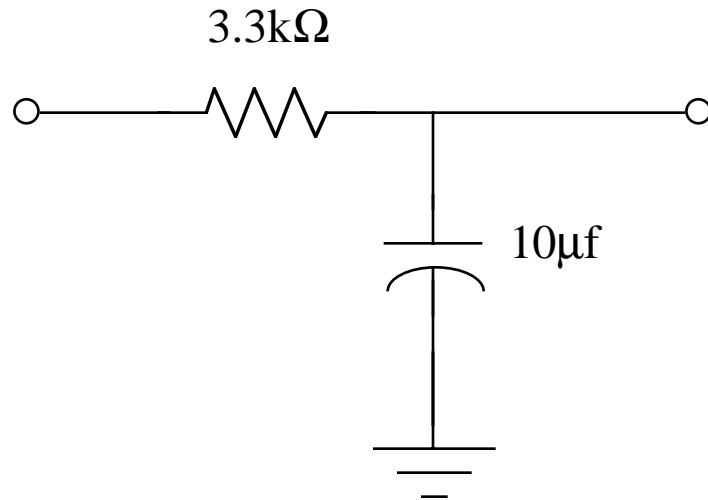
Figure 6. Filter circuit for sensor output (Optional)
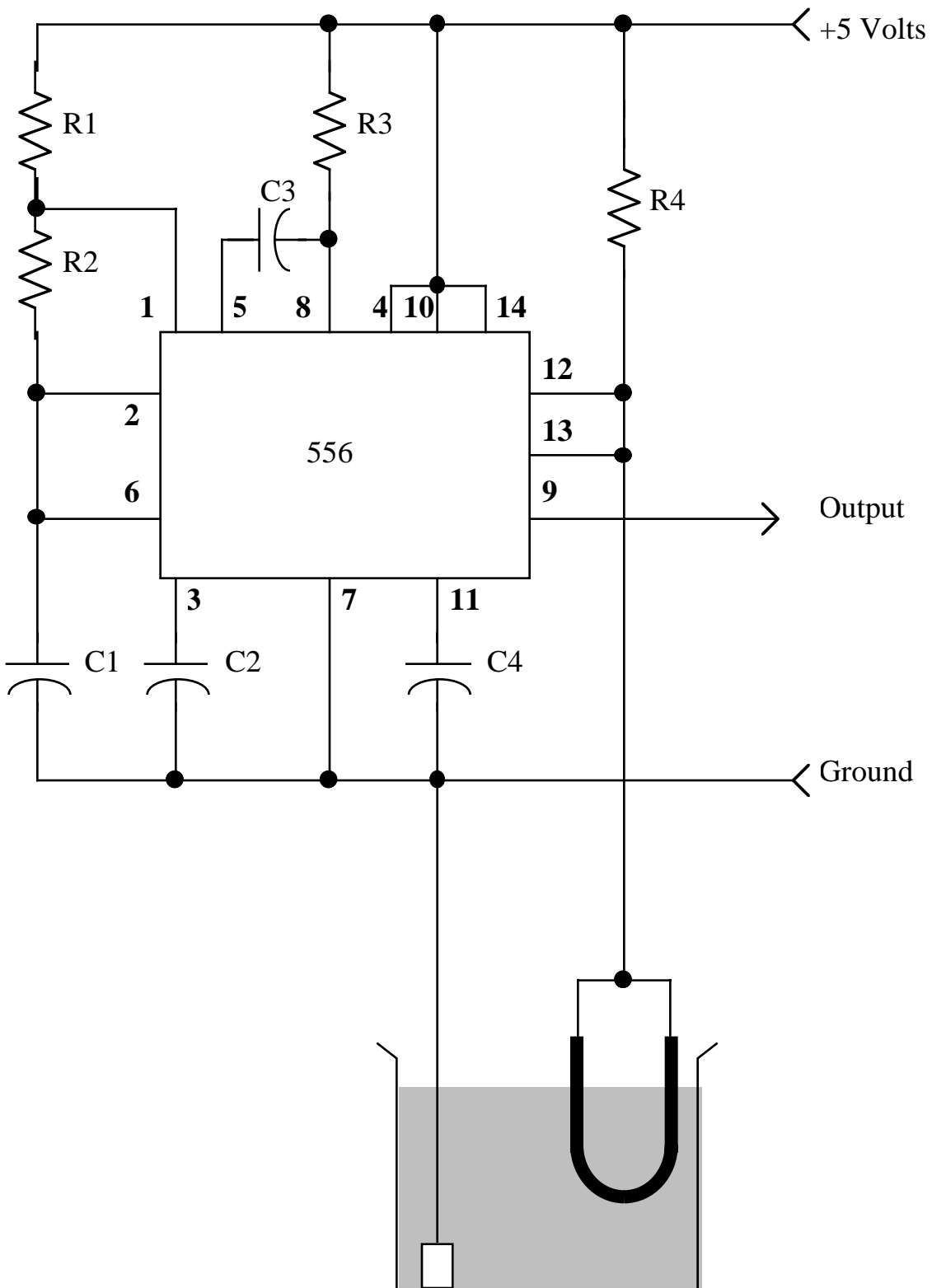
Figure 7. Water Level Detection Circuit

DATA SHEET FOR LAB 7

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Lab Group: _____

Data Table 1. Sketch of 555 oscillator output

Volts/div:

_____

Time/div

_____

Data Table 2. Sketch of capacitor voltage as a function of time.

Volts/div:

_____

Time/div

_____

Data Table 3. Sketch of output voltage as a function of time (R_B=short).

Volts/div:

_____

Time/div

_____

Data Table 4. Sketch of capacitor voltage as a function of time (R_B=short).

Volts/div:

_____

Time/div

_____

Data Table 5. Sketch of monostable circuit performance.

Volts/div (Channel 1):

_____

Volts/div (Channel 2):

_____

Time/div

_____

Data Table 6. Frequency as a function of water level.

water level	output frequency

Data Table 7. Water level sensor measurements

water level	output pulse width (oscilloscope measurement)	output voltage level (DC voltmeter)

Data Table 8. Sketch of water level sensor output.

Volts/div (Channel 1):

_____

Time/div

_____

REPORT SHEET FOR LAB 7

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Lab Group: _____

ANSWER THE FOLLOWING QUESTIONS:

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

ATTACH YOUR DATA SHEETS TO THIS REPORT!

For Part B:
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. Explain what happened when you shorted R_B in step 4?
4. What would happen if you replaced R_A with a thermistor similar to the ones you used in Lab 4? Describe the behavior of this circuit as a function of temperature.

For Part C:
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? Will these vary of you change the input voltage (the voltage from the signal generator)? Why or why not?

For Part D:
1. What is the range over which the duty cycle of your output waveform from the 556 changed as you varied the water level?
2. Explain how the DMM measurements varied as a function of water level. Remember that the waveform is varying and the DMM is set to DC volts. HINT: A DC voltmeter measures the average value of a waveform.