The 555 timer: Waveform shaping

Introduction:
      Oscillators are ubiquitous not only in research environments but also in our modern, technology-oriented society. Oscillators are used for communication, timing in computers, precision measurements of physical quantities, and much more. In this course your primary oscillator has been the function generator. In addition, you have experimented with square-wave relaxation oscillators, a Wien-bridge sine-wave oscillator, and waveform synthesis using digital counters. For most applications it is neither economical nor practical to dedicate a function generator that costs roughly $1200. In these cases it is useful to produce your own specific oscillator or pulse generator from integrated circuits (ICs), resistors, and capacitors.

      Nowadays, there is seldom any reason why you would need to design an oscillator from scratch, using an op-amp as you did in the previous lab for pedagogical purposes. A variety of ICs make the design of intermediate-frequency oscillators easy. A popular integrated circuit is the Intersil ICL 8038 function generator. It can produce precision sine, triangle, and square waves. This lab will not focus on the 8038 IC, but you should be aware that it and derivatives exist. Instead we will make use of another very versatile IC, the 555 RC oscillator/timer.

      The original 555 timer is a bipolar device. The 7555 is an improved 555, made with CMOS. It runs up to 500 kHz (versus 100 kHz for the 555), and its very high input impedances and rail-to-rail output swings can simplify designs. Below, I'll be referring to the 555 chip even though you may use the 7555 chip in the lab. For the purpose of this lab, the version of the 555 does not matter.

Legend:
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R   = Reset
TH  = Threshold
TR  = Trigger
DIS = Discharge
OUT = Output
V_CON = Control Voltage
V_CC  = Supply Voltage
GND = Ground (Common)
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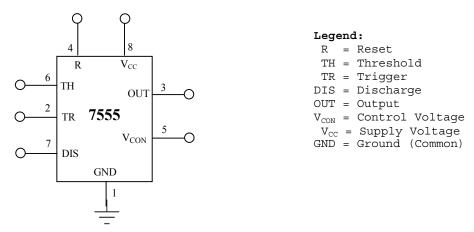
Fig. 1 555 timer pin out (revised)

Principle of operation:
      When wired as an oscillator, the 555's operation is similar to a relaxation oscillator; that is, there is a capacitor voltage that moves between two thresholds. Recall that the relaxation oscillator used the equivalent of a Schmitt trigger to provide these two thresholds. The 555 uses two comparators, comparing V_{cap} against 1/3 and 2/3 of V_{cc} to determine whether to flip the output state. The capacitor voltage is charged up or down by turning *on* or *off* a discharge transistor. This transistor pulls charge out of the capacitor, or when *off*, it allows the capacitor to
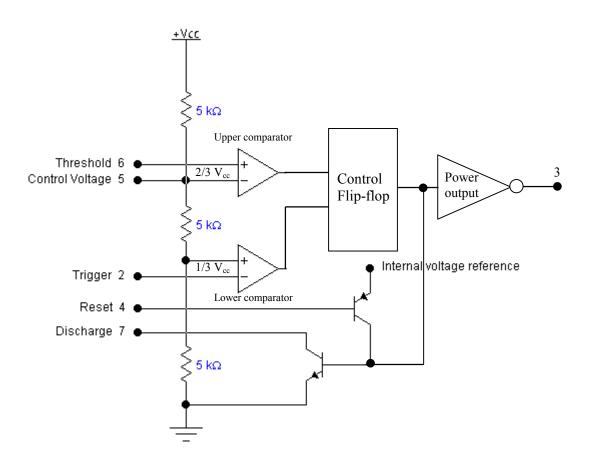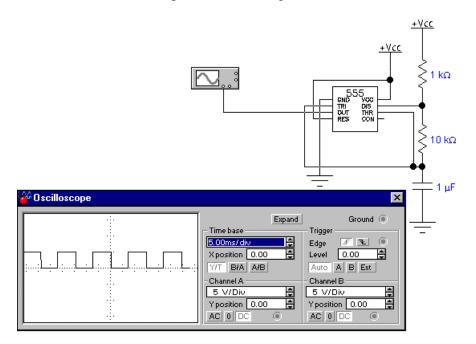
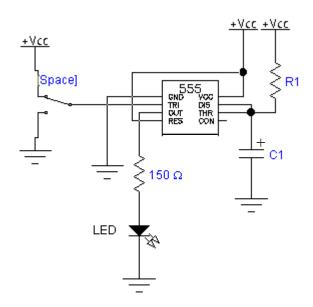Fig. 2 555 timer equivalent circuit

Fig. 3 555 timer wired as an oscillator

charge up toward the positive supply. Other inputs such as Reset and Control Voltage greatly enhance its functionality. The output can supply or sink up to 200 mA, a usefully large current that is sufficient to drive an LED or small loudspeaker.

Modes of operation: there's basically two of them: **monostable & astable**.

 Monostable: a circuit that produces an output pulse of fixed duration each time the input circuit is triggered. Monostables are useful in producing timing signals. For example, automatic garage-door openers often have a light that is turned on when the door is opened. The light stays on for a few minutes and then automatically turns off. This function can be provided by a monostable that is triggered when the door is opened. The light remains on for the duration of the output pulse. Using the 555 timer the duration of such pulses can be varied from tens of µs to hours.

555 timer wired for monostable operation

1) Wire the experiment in the schematic diagram, first using a 100 kΩ resistor and a 10 µF electrolytic capacitor. Remember to pay careful attention to the polarity! A pulser, e.g., a normally-open push button switch is connected from the timer's pin 2 to ground. Alternatively, you can use the function generator with pin 2 connected to a 'logic HIGH' output. The 555 is negative-edge triggered.

2) Using either a wristwatch or the oscilloscope, determine how many seconds the LED stays lit when the pulser is quickly pressed and released. Next, using roughly the various combinations of resistors and capacitors listed below, determine the pulse duration with the pulser. Write your answers below and compare them with the equation: $t_{pulse} = 1.1(RC)$.

Timing resistor (kΩ)	Timing capacitor (µF)	Measured pulse width (s)
100	10	
100	100	
1000	5	
1000	1	
330	10	
330	100	
620	5	
10000	5	

The results that you obtained should be consistent to within 10% as compared with the above equation. If not, chances are that the capacitor may be "leaky", so that it is difficult to charge and consequently it requires more time.
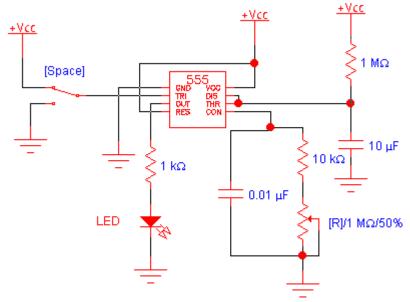
Things to Remember

For proper monostable operation with the 555 timer, the negative-going trigger pulse width should be kept short compared to the desired output pulse width. Values for the external timing resistor and capacitor can be determined from the above equation; however, one should stay within a range of resistances that avoids the use of large value electrolytic capacitors, since they tend to be leaky. Otherwise, tantalum or Mylar types should be used.

3) Next, demonstrate the reset function of the 555 timer, connected in monostable mode. Using the same circuit connect pin 4 to another pulser (push button switch). As before, the switch should be normally-open and when pressed it should drive pin 4 to LOW. Configure the timer to keep the LED on for about 11 seconds. Now, quickly press and release the pulser that is connected to pin 2 of the 555 timer, and then press and release the pulser that is connected to the timer's reset pin (pin 4). You should observe that the LED immediately goes out. Summarize your observations by drawing a timing diagram below for the trigger (pin 2), capacitor voltage (pin 7), reset (pin 4) and the output (pin 3). I recommend using the oscilloscope to observe the voltage across the capacitor.

Timing diagram illustrating the effect of the reset function of the 555 timer.

4) Now we will vary the duration of the timer's output pulse using the control pin.

    a. Wire the circuit in schematic diagram below, preferably using a 1 MΩ potentiometer instead of fixed resistors. If a pot is not available, a number of fixed resistors can be used instead.
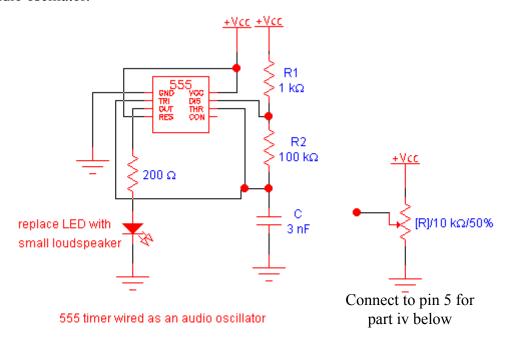

555 timer wired to demonstrate the control voltage function

    b. First temporarily disconnect the 10 kΩ resistor that is connected between the pot and the timer's control pin (pin 5). Determine how long the LED stays lit when the pulser is quickly pressed and released. It should be approximately 11 seconds, depending on the toloerance of the 1 MΩ resistor and the quality of the 10 μF capacitor.

    c. Reconnect the 10 kΩ resistor, after momenetarily disconnecting the power supply. Then adjust the potentiometer to about 100 kΩ, using your DMM, or used a fixed 100 kΩ resistor, and apply the power. Using the pulser, note how long the LED stays lit.

    d. Disconnect the power and adjust the pot to about 10 kΩ, or use a fixed 10 kΩ resistor instead. Reconnect the power and use the pulser, noting the time the LED stays ON.

    e. Try varying the pot's resistance to give different output pulse durations. Record your results below so as to indicate the range of pulse durations that you were able to attain.

Potentiometer resistance (kΩ)	Control Voltage (V)	Pulse duration (s)

Astable Multivibrator: a circuit that produces an oscillatory output. The frequency and duty cycle of the oscillator can be varied through the choice of resistors, capacitors, and a control voltage.

5) Wire the circuit schematic below which demonstrates how the 555 timer can function as an audio oscillator.

555 timer wired as an audio oscillator

Connect to pin 5 for
part iv below

In this mode the charging and discharging times of the capacitor generally are different depending on whether the transistor in Fig.2 is turned on or off.

$t_1 = 0.693(R_1 + R_2)C$ charging, output HIGH

$t_2 = 0.693R_2C$ discharging, output LOW

The frequency of oscillation is given by the inverse of the period, where the period is $t_1 + t_2$, or in terms of R and C

$$f = \frac{1.44}{(R_1 + 2R_2)C}$$

The purpose of the 200 Ω resistor is reduce the volume – feel free to adjust it to suit your needs. Examine the output waveform on the oscilloscope. Measure its duty cycle, *D.C.*, the ratio of the time the output is HIGH to the total period. Compare your result with the equation
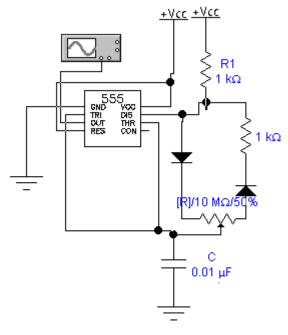
$$D.C. = \frac{t_2}{t_1 + t_2} = \frac{R_1 + R_2}{R_1 + 2R_2}$$

One can attain a nearly symmetrical square, having a duty cycle of 0.5 by making the value of R_1 much smaller than R_2.

Some other things to try:

i.   Gently place one finger of each hand on each side of the 100 kΩ resistor. Does the tone's pitch increase or decrease? Explain your answer.

ii.   Disconnect the wire from pin 4. Does anything happen? Explain your answer.

iii.   Now ground pin 4. What happens and why? Remove the timer's reset pin from ground. Now what happens? This "gating" technique is very useful for alarm circuits.

iv.   Connect a simple voltage divider to the control pin (pin 5), as indicated in the above figure. How are the frequency and duty cycle affected? This is a zeroth-order implementation of a voltage-controlled oscillator.

6) There exist many circuits that permit control over the timer's output frequency or, conversely to make the frequency independent so that the duty cycle can be easily varied over a wide range while keeping the output pulse rate constant. Wire the following circuit and verify that the duty cycle can range from about 0.01% to 99.99% with little change in frequency. (You can substitute a 1 MΩ pot for the 10 MΩ pot shown in the diagram but realize that there will be a corresponding factor of 10 decrease in the duty cycle range.) Refer to Fig. 2 and explain how this circuit works and the role played by the diodes.

Adjusting the duty cycle of the 555 timer

Things to remember

While the 555 timer does make stability and a reasonably accurate frequency a practical reality in a simple circuit, more precise timing sources, such as the power-line frequency or a crystal oscillator, should be considered if you need extreme accuracy in your circuit. For less than 1% accuracy, the 555 timer is an ideal choice. For an accuracy better than 0.1%, consider digital or crystal techniques.

Occasionally the 555 will suffer from jitter problems on its output if the supply-voltage variations are rapid with respect to the timing cycle. Bypassing the Control input (pin 5) to ground with a 0.1 μF capacitor usually helps a lot. In extreme cases, you may need to improve the supply filtering and regulation.