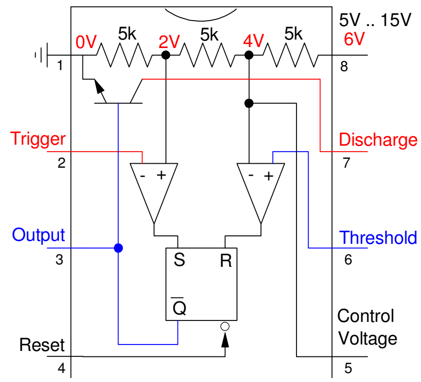
555 Timers



555 Timer. The name comes from the three 5k resistors between pins 1 and 8

Introduction:

Analog circuit design essentially involves designing circuits without resorting to a microcontroller. Some of the advantage of not using a microcontroller are:

- There's no program to crash. The circuit will work on power up.
- The circuit can respond in micro or nano seconds. You don't have to worry about program execution speed.
- Aliasing, quantization noise, and other problems with sampling are avoided.
- The resulting circuit can be very inexpensive.

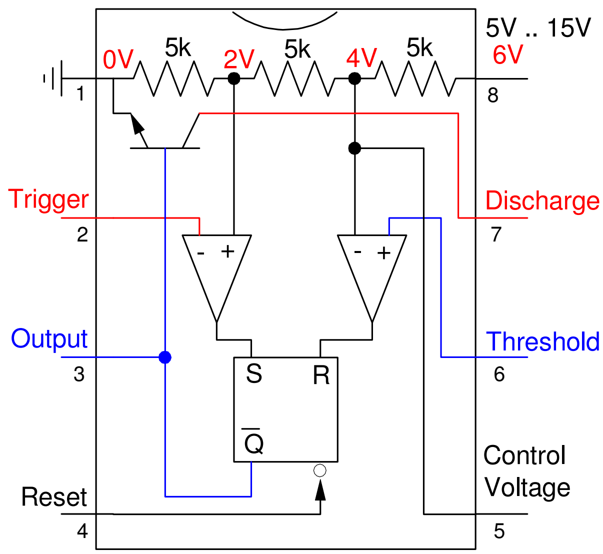
One of the more useful tools in designing an analog circuit is a 555 timer. With it, you can build:

- An oscillator - allowing you to keep track of time, make lights blink, speakers buzz, etc.
- An oscillator whose frequency depends upon temperature, light, water, etc.
- A voltage-controlled oscillator - allowing you to make siren noises, and
- A one-shot - allowing you to do something one time after an event (such as turn on a light for 30 seconds when motion is detected.)

In your upcoming labs, it will be very useful to have something to make your LEDs blink, speakers buzz, and so on. Likewise, we're going to start with the 555 timer - before we're really ready to understand how exactly it works. For now, concentrate on using a 555 timer as a tool to generate pulses and square waves. When we get to transistors and operational amplifiers, you should understand how it works better.

555 Timer:

555 Timers get their name from the use of three 5k resistors in series. These resistors create two reference voltages equally spaced between ground and the power supply (6V in this example).

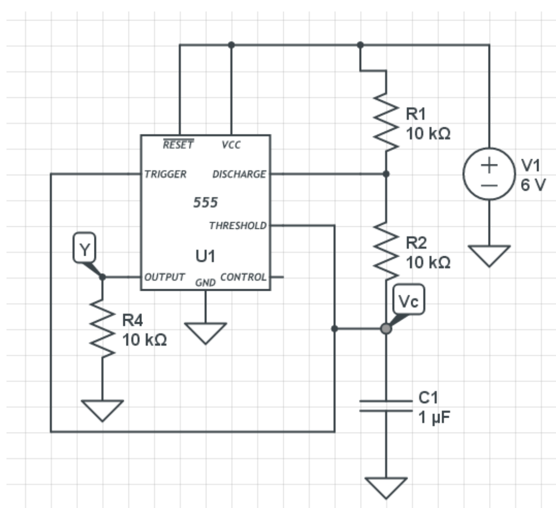


The function of the pins are as follows (assuming a 6V power supply):

- Power and Ground: self explanatory. Power can be anything from 5V to 15V.
- Trigger: When Trigger < 2V, the SR flip-flop sets and the output goes high.
- Threshold: When Threshold > 4V, the SR flip flop clears and the output goes low
- Control Voltage: Allows you to change the threshold voltage from 4V if you like
- Discharge: When the output is low, Discharge is shorted to ground through a transistor. Otherwise, Discharge is a floating pin.

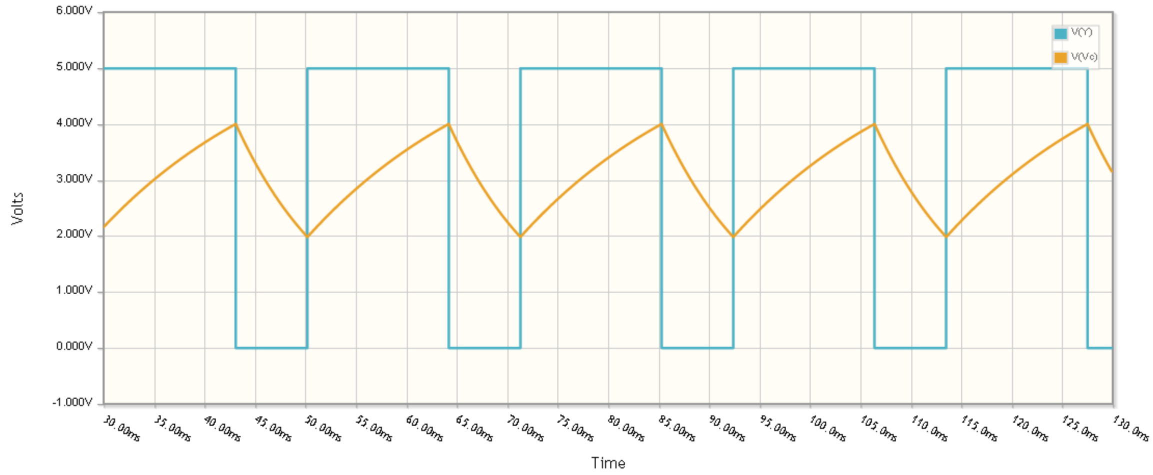
555 Oscillator (take 1):

One of the two main uses of a 555 timer is an oscillator, with a CircuitLab circuit shown below.



555 Timer in CircuitLab.
C1 charges through R1 and R2. It discharges through R2

you get the following voltages:



Voltage at Vc (orange) and Y (output = blue)

The way this circuit works is as follows:

Assume C1 is initially discharged (V_{THR} = 0V). This results in:

- Current flowing through R1 and R2, charging the capacitor up to +6V.
- V_{TRI} < 2V. This makes the SR flip-flop's input is S=1, R=0, and the output is brought high.
- DIS is floating while the output is low, and the capacitor charges up to +6V through R1 and R2.

When 2V < V_{TRI} < 4V, the SR flip flop has an input of S=0, R=0, and the output remains unchanged (high in this case).

When V_{THR} > 4V, S=0 and R=1, clearing the flip flop. This results in

- The output going low
- The DIS being shorted to ground (true whenever the output is low), and
- The capacitor discharging to 0V through R1.

When V_{THR} drops below 2V, the process then repeats, creating an oscillator.

Note on the voltage waveform:

- The voltage on the capacitor is charging up to +4V and then discharging down to +2V.
- The square wave is not symmetrical

The latter is due to current flowing through R1 and R2 to charge the capacitor, while it only has to flow through R1 to discharge it.

Calculations: Determine the period of the square wave in the above example:

Solution: The equation for the voltage across a capacitor as it discharges is

$$V = V_0 \cdot \exp\left(\frac{-t}{RC}\right)$$

Assume the capacitor is initially 4V. The time it takes to discharge down to 2V is

$$2 = 4 \cdot \exp\left(\frac{-t}{RC}\right)$$

For C = 1uF and R = 20k

t1 = 13.9ms

For C = 1uF and R = 10k

t2 = 6.9ms

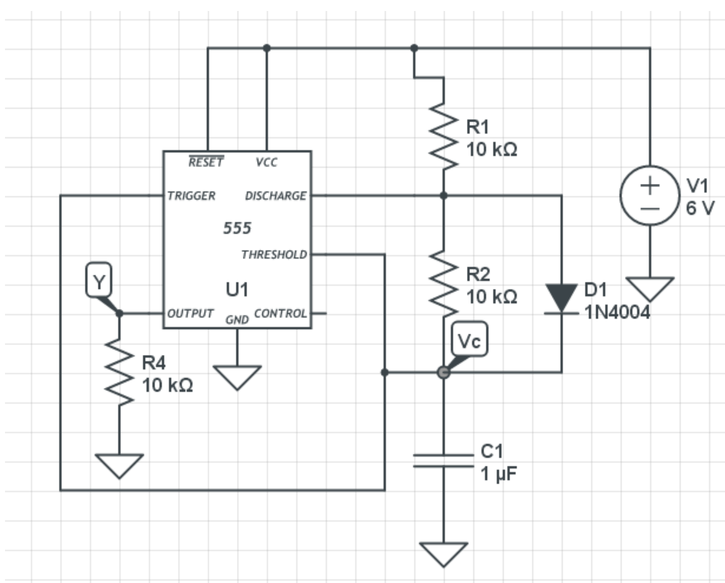
The period should then be

t1 + t2 = 20.8ms

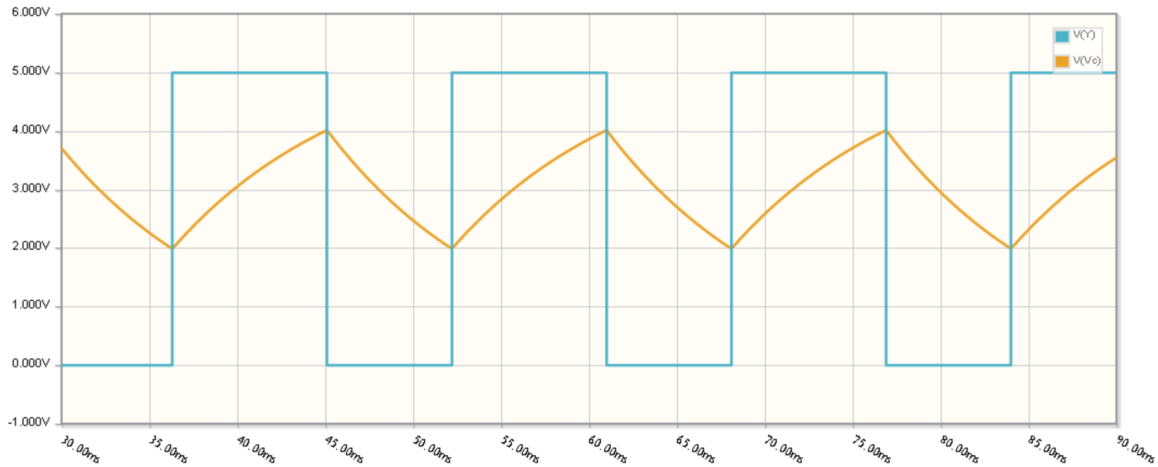
These numbers match up with the Circuitlab simulation.

555 Oscillator (take 2):

A diode is a device which allows current to flow one way - hence its symbol is an arrow showing the direction of current flow. Suppose you short out R1 with a diode as follows.



50% Duty Cycle Square Wave (approx)
C1 charges through R1 and discharges through R2



Voltages for 555 timer: Output (blue) and Vc (orange)

Now, C1 is charged up to +6V through ust R2. Current flows through the diode, bypassing R1.

When VDIS = 0V, C1 is still discharged through R1. The diode does not allow current to flow in the up direction.

The net result is

- R1 controls the time that the output is +6V (and the capacitor is charging up)
- R2 controls the time that the output is 0V (and the capacitor is discharging)

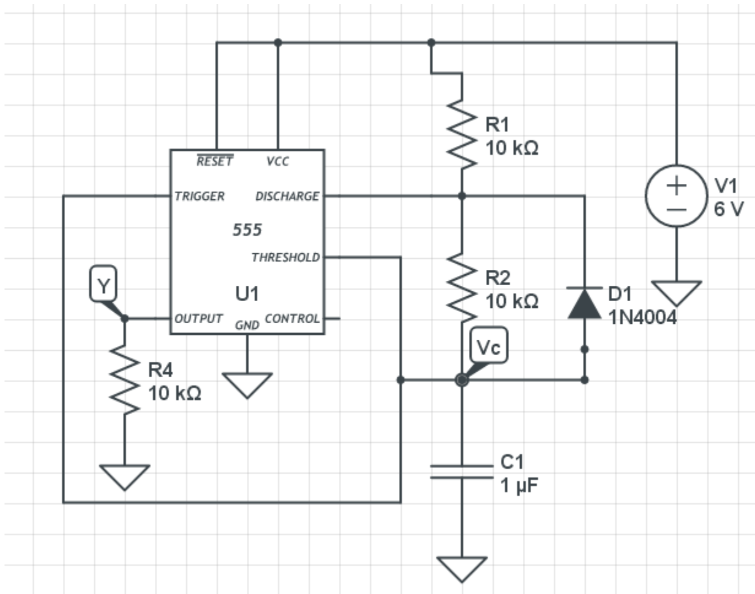
With R1 = R2 = 10k, you get a more symmetric square wave as shown above. Note that it is not exactly symmetric: the diode has a slight voltage drop across this (more on this later). You can compensate by adjusting R1 and R2 if you like.

555 Oscillator (take 3):

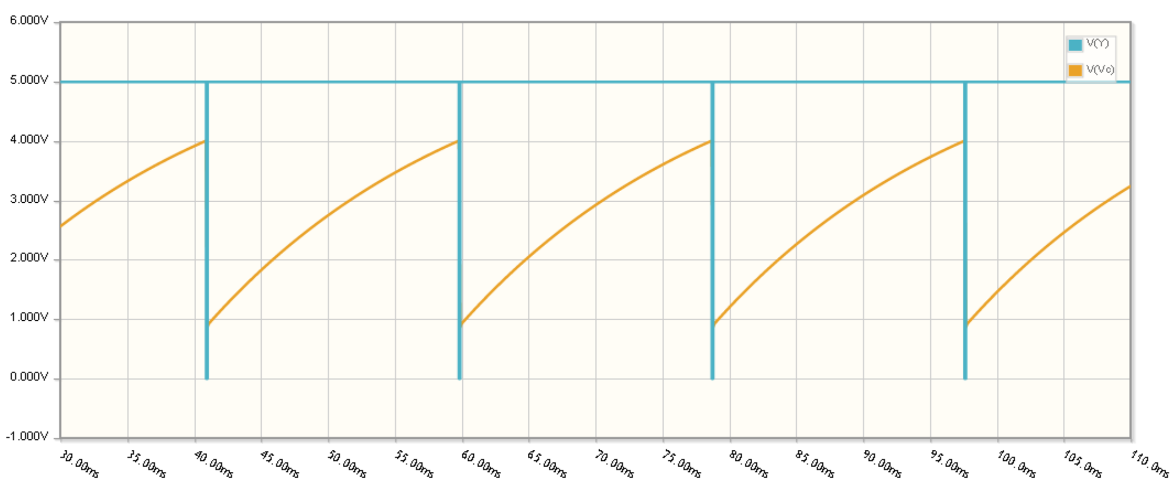
Finally, assume you reverse the direction of the diode. In this case,

- The capacitor charges up to +6V through R1 and R2. However
- The capacitor discharges down to 0V through the diode.

It takes almost no time to discharge the capacitor - the diode will allow almost unlimited current (in theory at least) in the direction the arrows point. The resulting waveform is a sawtooth wave



Example #3: Reverse the direction of D1 and you produce a sawtooth wave



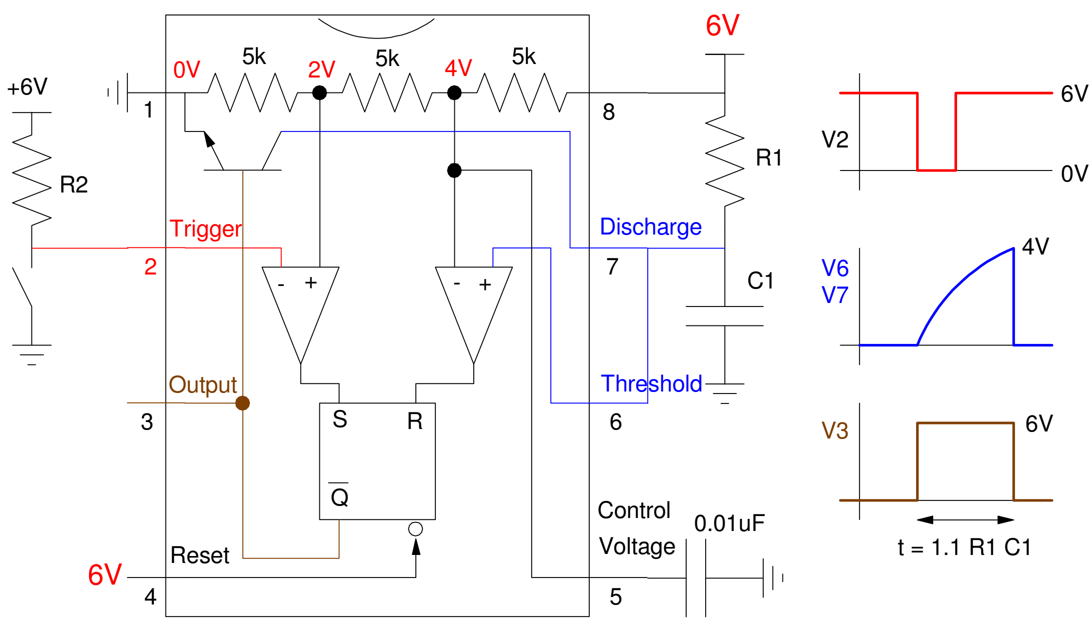
Votlage at Vout (blue) and Vc (orange).

555 Timer and Sensors:

Note that if you vary R1, R2, or C1, you'll vary the frequency of the square wave. This lets you build a circuit where the frequency is related to temperature, pressure, humidity, magnetic field, etc. Just replace one of these components with a sensor.

555 One Shot

This is actually a little simpler than an oscillator. For example, design a circuit which outputs a single 10 second pules when a button is pressed.



Initially, R_2 pulls V_{TRIG} up to +6V.. This keeps S=0 and the output V_3 is low. While V_3 is low, the transistor turns on and shorts C_1 to ground.

When you press the button, V_{TRIG} is grounded, setting the flip flop, and V_3 goes high. This also turns off the transistor and allows C_1 to charge up to +6V.

When V_{C1} reaches +4V, R=1 and the flip flop is cleared again.

The net result is a single pules at the output, with a duration equal to the time it takes C_1 to charge up to +4V. In theory, this should be:

$$V_{C1} = 4V = 6\left(1 - \exp\left(\frac{-t}{R_1 C_1}\right)\right)V$$

$t = 1.1\ R_1\ C_1$

For 10 seconds, let

C1 = 100uF, R1 = 91k Ohms