Notes on the 555

The Signetics 555 timer may be the most popular integrated circuit ever designed. It certainly is if we disregard op amps. The need it addresses comes up repeatedly in electronics design—a simple and versatile timing circuit. Timing in analog electronics is almost always based on charging and discharging a capacitor. The characteristic voltage curve of a capacitor and resistor are one of the first things I discuss in any course.

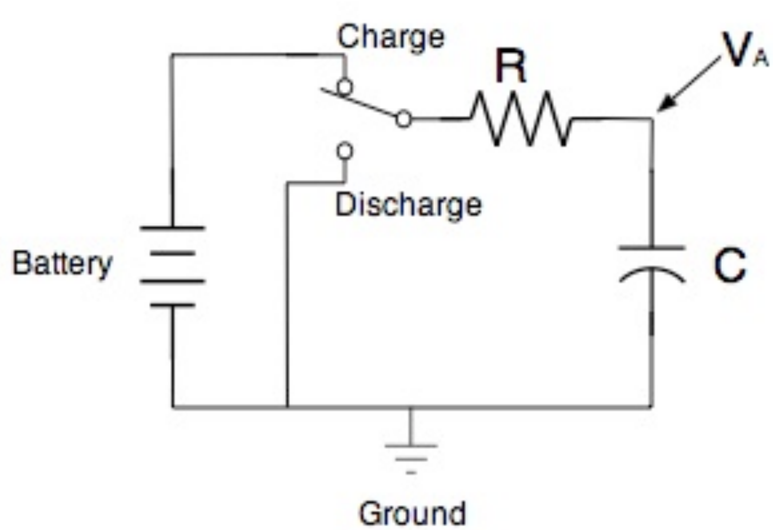


Figure 1.

Figure 1 shows the basic capacitor charging circuit. When the switch is placed in the charge position, current flows through the resistor R and is stored in the capacitor C. As the capacitor charges, the voltage measured between V_A and ground increases, so the voltage across the resistor decreases. Ohms law means as the voltage across the resistor decreases, the current also decreases, so the charging process slows down. Figure 2 shows how the voltage at V_A changes over the charging cycle:

The time is indicated in units τ which is the time constant. The time constant is defined as resistance (in ohms) times capacitance (in farads). Note the reading after one time constant, 63.2% of the full voltage. The charge voltage will never actually match the battery voltage, as the charging rate just keeps slowing down. However, after 5 time constants, we call the capacitor fully charged, as practically no current is flowing.

When the switch is moved to the discharge position, the energy stored in the capacitor can come back out. Again through the resistor with its current control ability. The voltage curve you get if the capacitor was fully charged is shown in figure 3. Not too surprisingly, after one time constant the voltage is down to 36.8% of the full value.

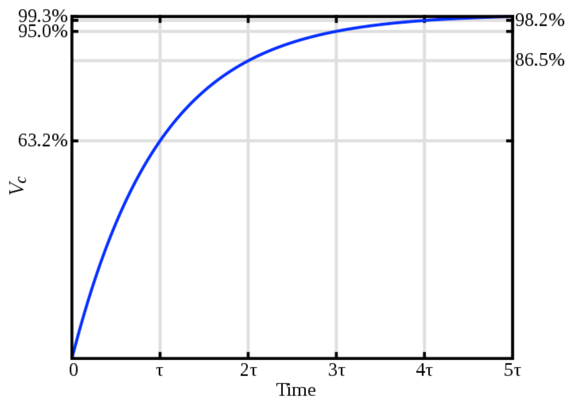


Figure 2. Capacitor voltage while charging.

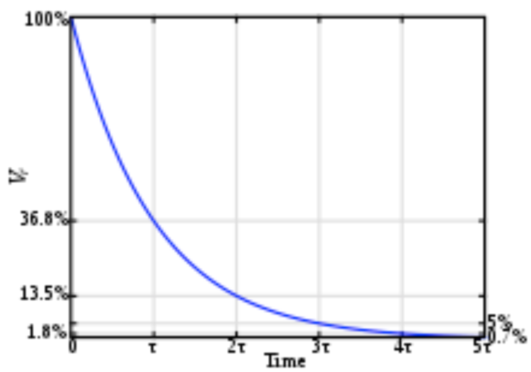


Figure 3 Capacitor voltage while discharging.

We can build a timer by starting a charge cycle and detecting when the charge reaches a target voltage. We then need to discharge the capacitor to do it again. This can easily be done by a shunt to ground as in figure 4. The circuitry to do this is provided in the 555.

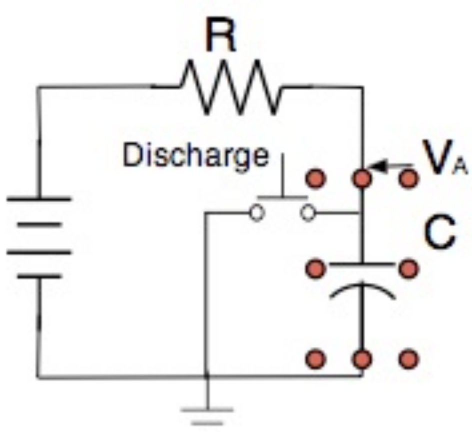


Figure 4.

Components of the 555.

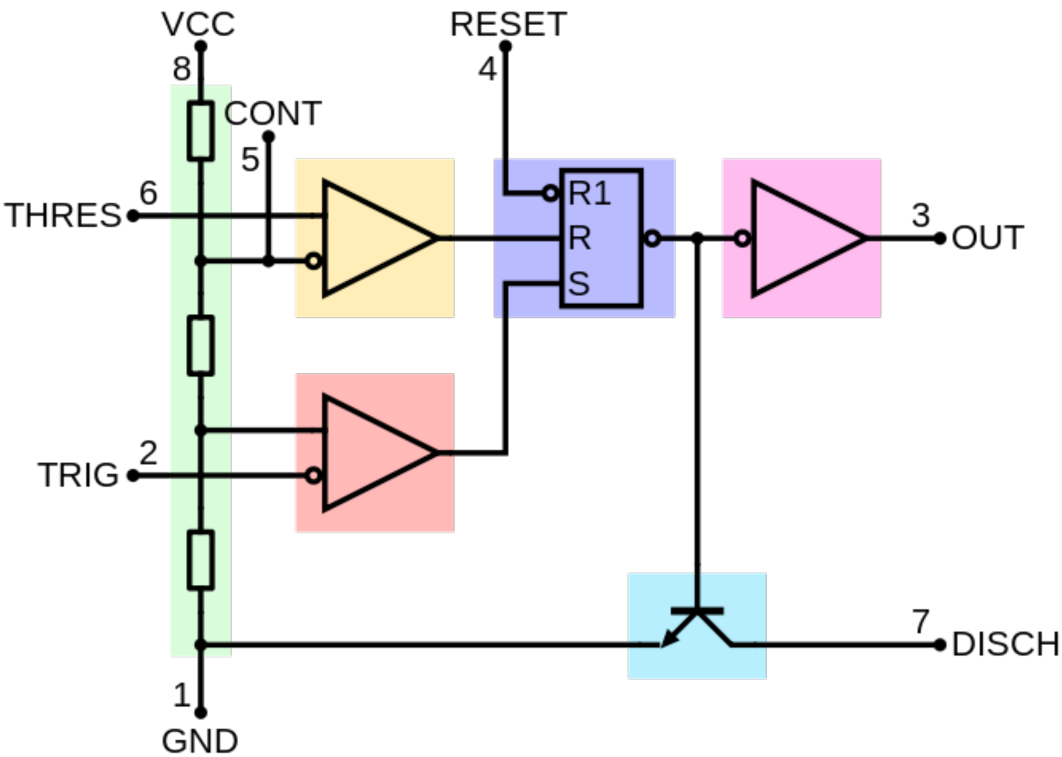
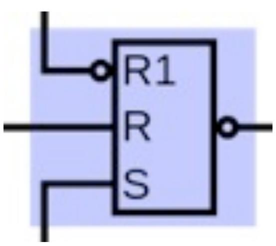


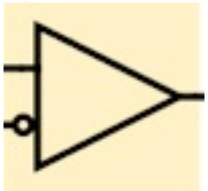
Figure 5. Block diagram of 555. (Courtesy Wikipedia)



The heart of the 555 is the rectangular item in figure 5, which is known as an R-S flip-flop. This is a memory cell which can be set to on or off . Circuits like this are called logic circuits, and the logic is described as 1 or 0. Normally we define on as a logic 1 and off as a logic 0. However, it is sometimes convenient[1] to define 1 as off and 0 as on. This is called inverted logic. The points in a diagram where the logic inverts are marked with little circles. The output of the R-S flip-flop is inverted in the 555, which affects the transistor attached there. That transistor acts as a switch connected between ground (pin 1) and pin 7. With this inverted logic, the switch is closed when the flip-flop is off. There is another little circuit that re-inverts the flip-flop output and connects that to pin 3. So pin 3 shows the state of the flip-flop.

There are three inputs to the flip-flop, and the latest determines its state. The resets (R and R1) will turn the flip-flop off. Note R1 is inverted, so grounding the pin 4 performs the reset. (This is why most circuits show pin 4 connected to the positive power. We don't want any resets.) The set input (S) turns the flip-flop on.

[1] i.e. cheaper.



The circuit elements shown as triangles with two inputs are comparators. As the name might imply, these compare their inputs and are either on or off depending on which input has the higher voltage. In figure 5, one input of each comparator is identified with the inverting circle. When the voltage on this input is less than the other one, the comparator turns on. One comparator will set the flip-flop, the other reset it. Note that they should not be both on at once.

The small rectangles represent resistors. They have a value of 100kΩ, but that's not important right now. What is important is they are all the same. They divide the power supply voltage by 3 and set the threshold voltages where comparators flip. The comparator connected to pin 6 (thresh) will turn on and reset the flip-flop when the input is higher than two thirds of the supply voltage (V_S). The comparator connected to pin 2 (trig) will turn on when the input is less than one third V_S and will set the flip-flop. Pin 5 connects between the upper two resistors. This allows the use of a control voltage to change the thresholds, but it's a bit fiddly because the top of the resistor chain is always connected to the power. Most circuits connect a capacitor here to prevent electrical interference from messing up the thresholds. (Usually, there's a capacitor on pin 8 for the same reason.)

All of this leaves two rules for the 555 action:

When pin 6 is below $2V_S/3$ and pin 2 is brought below $V_S/3$, pin 3 will turn on and the transistor will conduct current to ground.

When pin 2 is above $V_S/3$ and pin 6 is above $2V_S/3$, pin 3 will turn off and the transistor will stop conducting.

We can now use the transistor on pin 7 to switch the voltage to the capacitor, and pins 2 and 6 to switch the transistor on and off. Figure 5 shows how.

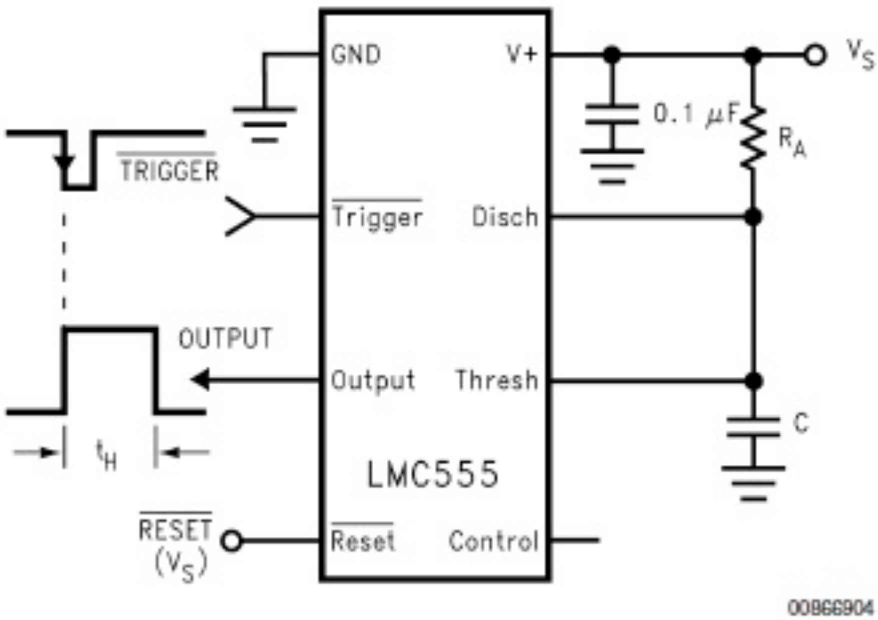


Figure 6.

Figure 6 is the basic connection of the 555 as shown on the manufacturer's data sheet. The capacitor C and resistor R_A establish the timing. Note that both pin 6 and 7 are connected between the resistor and capacitor. When the power is first turned on, the flip-flop will be off and the transistor connected to pin 7 turned on—this keeps the capacitor from charging because it is shorted to ground. When pin 2 is briefly brought low (a push button to ground will probably do) the flip-flop turns on and the transistor on pin 7 turns off. Current from R_A can now charge the capacitor, and it will follow the curve of figure 2. When the voltage on the capacitor reaches 2/3 V_S, the comparator on pin 6 will turn the flip-flop off. The transistor again shorts the capacitor to ground and it discharges very quickly. Figure 7 graphs all of this.

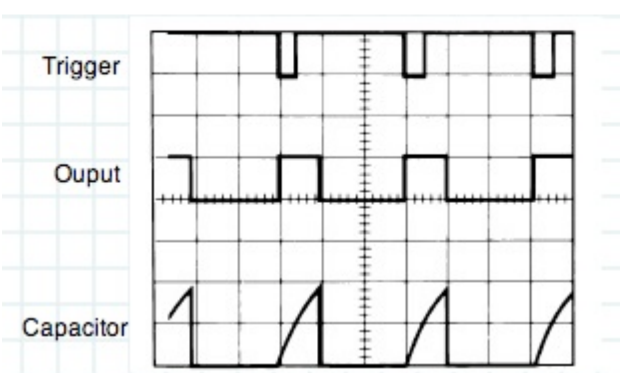


Figure 7.

The circuit in figure 6 is known as a monostable multivibrator. It produces a pulse of a known duration from a short trigger—a perfect timing unit. The duration of the pulse is 1.1 R_A C. Very large capacitors can be used. The only limitation of this circuit is the trigger must go high before the delay is finished.

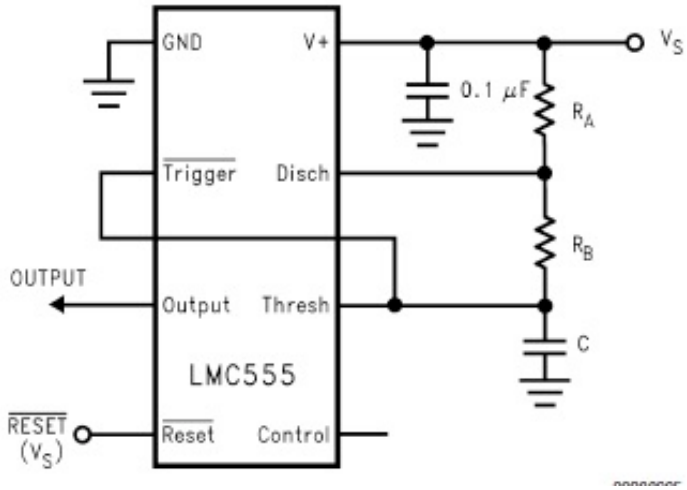


Figure 8.

In figure 8, the circuit is modified a bit. There is a second resistor R_B connected between the capacitor and R_A. The discharge transistor is then connected between the two resistors. This means R_B will determine the discharge time and the sum of both resistors will determine the charging time. In addition, the trigger input is connected to the top of the capacitor. Since the capacitor is discharged when the power is turned on, the 555 will immediately be triggered and the capacitor will start charging. When it reaches 2/3 V_S, it the discharge will begin, but at a rate set by R_B. When the capacitor voltages gets down to $V_S/3$, the 555 will trigger again. Thus the output will osculate. The time for a cycle is the sum of the charge time and discharge time.

Charge time:

$$t_1 = 0.693\,(R_A + R_B)C$$

Discharge time:

$$t_2 = 0.693\,(R_B)C$$

Total cycle:

$$T = t_1 + t_2 = 0.693\,(R_A + R_B)C$$

The frequency of oscillation is

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2\,R_B)\,C}$$

Duty cycle:

$$D = \frac{R_B}{R_A + 2R_B}$$

Figure 8 is an astable multivibrator.

The internet is full of circuits based on the 555 in these two configurations. Modifications are usually about getting a proper trigger or using the 555 output somehow. Here are a couple of examples:

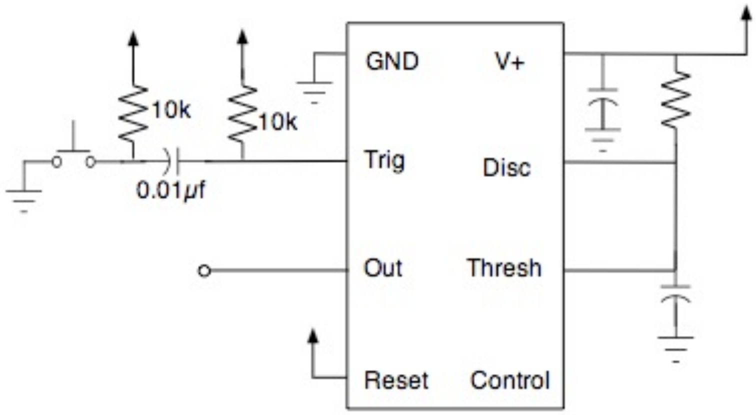


Figure 9.

Figure 9 shows one way to get a short trigger pulse from a button push. If the button were connected directly to the trigger input, the output would stay high until the button was released.

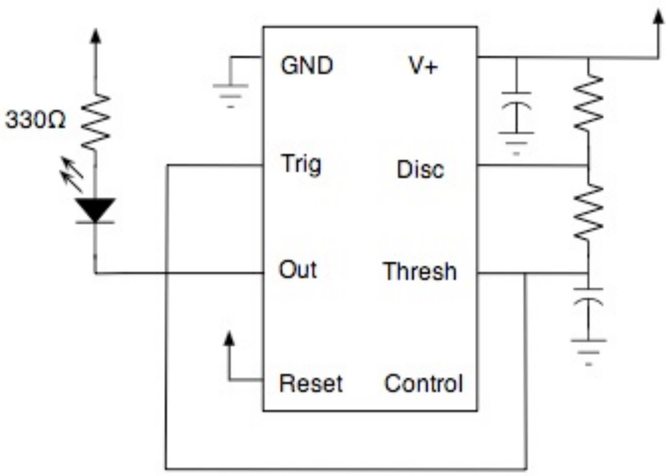


Figure 10.

Figure 10 shows how to flash an LED.