Electronics 101.11
The 555 timer

Delays, pulses, buzzes, and beeps

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Dave's career started in the 8-bit days, with the Z80 and 6502, and he's been working with computers ever since. Check him out at: **daveastels.com** and **learn.adafruit.com**

Few integrated circuits have been used as much, for as long, and for such a variety of applications, as the humble 555 timer. You can find it in devices ranging from toys to spacecraft. The 555 has been in continuous production since the early 1970s. It is available in several varieties: there are bipolar and CMOS versions that are much the same, but vary in small (but sometimes significant ways); we'll just be dealing with the basic bipolar version in this article. The 555 is also packaged in single (555), dual (556), and quad (558) packages. The 558 is no longer in production, but you can easily get the 555 and 556 in both through-hole and surface-mount packages.

Let's peel back the black plastic packaging and take a peek at how this ubiquitous ship operates behind the scenes.

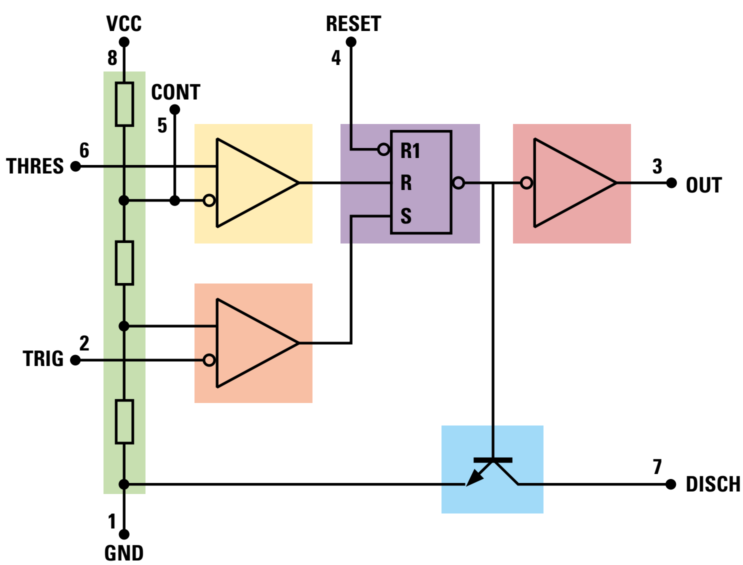


Figure 1
A functional view inside the 555

HOW IT WORKS

The 555 can operate with supply voltages between 4.5 and 15 volts. The voltage has no impact on timing characteristics.

Figure 1 shows an abstract view of the internals of a 555. We'll look at each block in turn, most of which we have already discussed in previous issues.

Voltage divider

Shown in green in **Figure 1** is a voltage divider. This is constructed from three identical resistors and stretches between VCC and GND. It provides two reference voltages: 1/3 VCC and 2/3 VCC.

This divider is the key to the VCC-independent behaviour of the 555. The circuit operates relative to the voltages from this divider, which are relative to VCC.

Comparators

The voltages provided by the voltage divider (1/3 and 2/3 VCC) connect to a pair of comparators.

The 1/3 VCC connects to the non-inverting input of the trigger comparator (highlighted in orange). Its inverting input is connected to the TRIG input (pin 2). The 2/3 VCC connects to the inverting input of the threshold comparator (in yellow). That comparator's non-inverting input connects to the THRES input.

When the TRIG input drops below 1/3 VCC, the trigger comparator's output goes high. Conversely, when the THRES input goes above 2/3 VCC, the threshold comparator's output goes high.

There's one other wrinkle: the inverting input of the threshold comparator (which is connected to 2/3 VCC from the voltage divider) is also connected to the CONT input (control) which allows external circuitry to directly override the voltage THRES is compared against. This also impacts the voltage to which TRIG

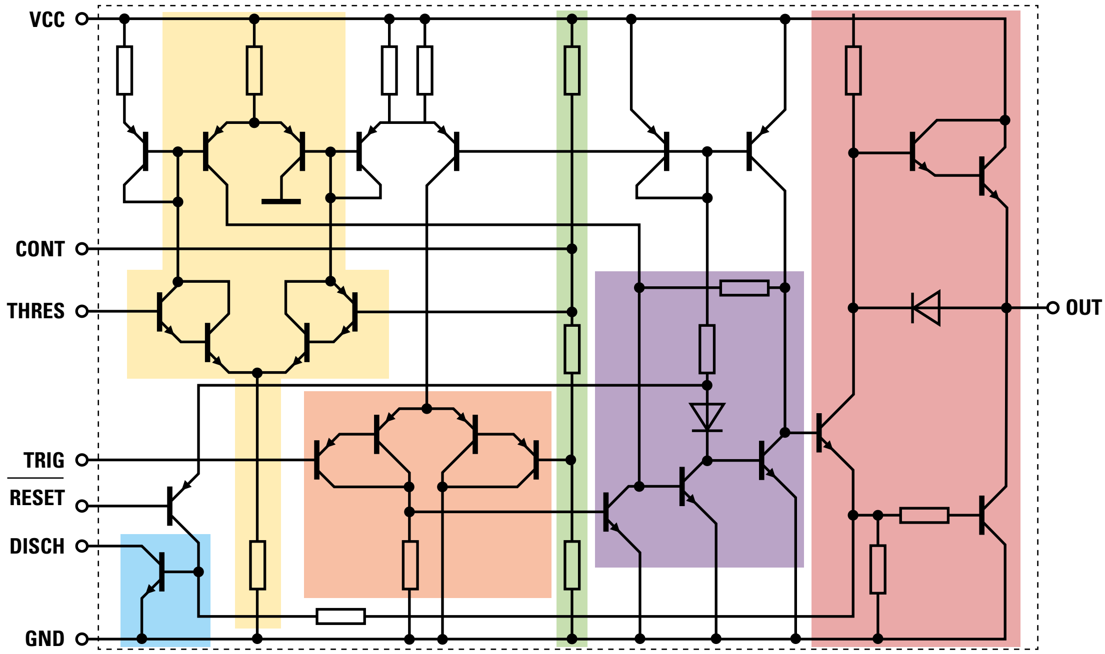


Figure 2 The schematic of the 555

QUICK TIP

The 555 is one of the most produced and used integrated circuits in history. It first appeared in 1971, and in 2003 it was estimated that one billion were being made each year.

is compared; since the resistors are of equal value, TRIG will be compared to half the voltage on CONT. In most circuits, CONT is not used and is connected to ground through a 0.01 μF capacitor to shunt any random noise to ground.

> **This divider is the key to the** VCC independent behaviour of the 555

RS flip-flop

We haven't talked about flip-flops in previous issues. They are a very basic digital logic memory element. They can have their state set to high or low (i.e. true or false) and they retain it until it is otherwise set. There are various types of flip-flops that vary as to how their state is changed. In the case of the 555, the flip-flop is a simple reset-set style, aka an RS flip-flop. When the R(eset) input goes high, the flip-flop's state switches to low. When S(et) goes high, the state switches to high. Note that the state changes when the inputs change from low to high, not when they *are* high. As noted in **Figure 1**, the output of the flip-flop (highlighted in purple) is inverted, so it's the opposite of the flip-flop's internal state. The third input to the flip-flop is R1, which resets the flip-flop to a low state regardless of other inputs. The circle on it denotes that it is active low. When it is low, the flip-flop is forced to a low state and remains so until the reset input goes high again. When it is high, the R and S inputs control the state. The R1 input connects directly, and only, to the RESET input of the 555. This is normally connected to VCC if it's not being used.

The R input is driven by the threshold comparator, while the S input by the trigger comparator. The result of this is that the state switches to high when the TRIG input drops below 1/3 VCC, and to low when THRES exceeds 2/3 VCC.

Output buffer

The inverted output of the flip-flop is again inverted and buffered to drive the OUT pin (pink in diagram). Thus OUT mirrors the internal state of the flip-flop.

Transistor switch

The final piece of the 555 is an NPN transistor (cyan in diagram) whose emitter is connected to GND, and whose collector connects directly (and only) to the DISCH pin. As we will see, this is used to discharge the timing capacitor. The transistor is controlled by the signal between the flip-flop and output buffer, i.e. the inverse of the flip-flop's internal state. So, when the flip-flop is reset, the transistor is on, and DISCH is connected to GND.

Schematic

Figure 2 drills in further, going from block diagram to discrete components. Each block is highlighted using the same colours. For all of its usefulness and flexibility, it is actually a rather simple circuit. If you want to explore further at this level, Evil Mad Scientist (**evilmadscientist.com**) sells a 555 kit using →

YOU'LL NEED

- **Solderless breadboard**
- **Jumper wires**
- **555 ICs (at least two)**
- **Various resistors and capacitors as shown in the circuits, as well as more to experiment with; getting a variety pack is best**
- **1 100 kΩ variable resistor (potentiometer)**
- **4 or 8 Ω speaker**
- **Piezo buzzer**
- **Several push-button switches**
- **Arduino Uno, or similar board**
- **220 Ω resistor and LED to connect to the output of various circuits**

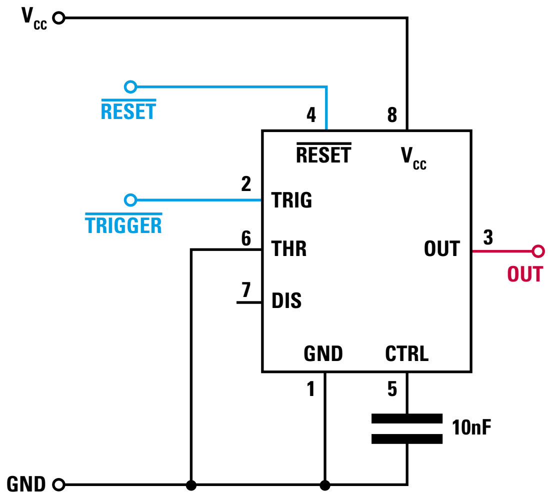


Figure 3 A 555 used in bistable mode

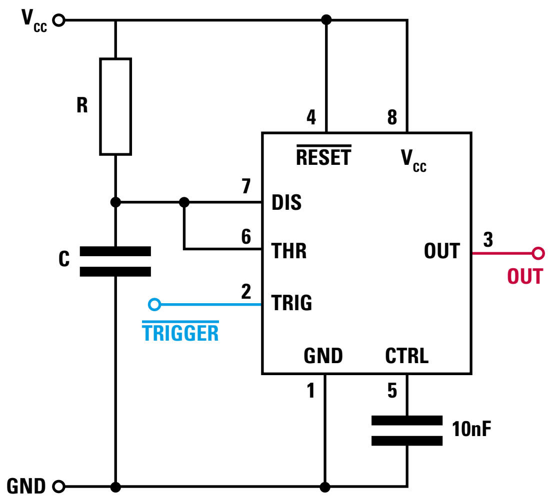


Figure 4 A 555 used in monostable mode

QUICK TIP

A 555 can be used as a small flip-flop with a flexible power supply.

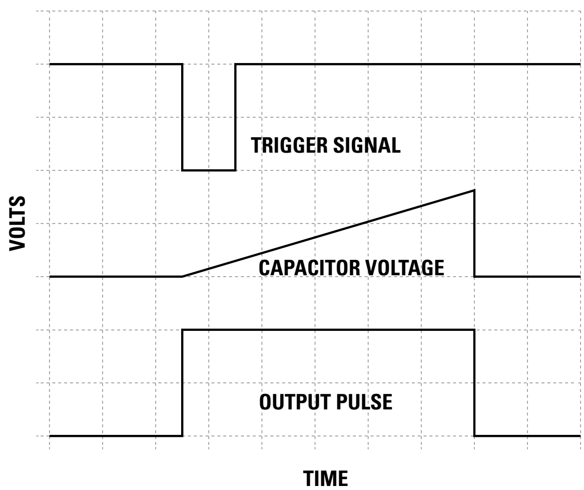


Figure 5 Significant signals in the monostable circuit

discrete, through-hole components. It's available directly from them, as well as some other sellers of electronics kits and parts.

The 555 supports three primary modes of operation: bistable or switch, monostable or one-shot, and astable or oscillating.

BISTABLE

We will begin with the simplest mode. Bistable mode uses the 555 as a simple switch by using the flip-flop more or less directly. This is done by rendering the THRES input useless by connecting it directly to GND. We then add a pull-up resistor to each of RESET and TRIG. Making RESET low resets the flip-flop, taking OUT low. Making TRIG low (which will be less than 1/3 VCC) switches the flip-flop's state to high and takes OUT high. Note that the inputs aren't completely symmetrical: RESET will take priority, despite what happens on the TRIG input.

Figure 3 shows an example circuit. Pushing the buttons controls the 555's state.

MONOSTABLE

Monostable means that the circuit is stable in one state. We can force it into the other state, but it will return to the stable state as soon as it can. **Figure 4** shows the circuit. Notably, THRESH and DISCH are connected together and to VCC through a resistor (R) and to GND through a capacitor (C). When TRIG drops to low (i.e. below 1/3 VCC), the flip-flop's state changes to high. One effect of this is to turn off the discharge transistor. That allows C to charge through R. When it has charged to the point that the voltage across it is 2/3 VCC, the threshold comparator flips its output, resetting the flip-flop. That takes OUT low (back to the stable state) and turns on the discharge transistor connecting DISCH to GND, which drains the charge from C and takes the voltage at THRES to 0 (since it's connected to DISCH). The 555 is now happily back in its stable state until TRIG once more switches from high to low.

The time that the output stays high is the time it takes the capacitor to charge enough to change the voltage across it from 0V to 2/3 VCC. Recall our discussion of capacitors back in issue 10. There, we said that, based on the charging curve of C through R, in time R × C the voltage across the capacitor will be at 63% of VCC. That's close enough to 2/3 for most purposes, so we say that the pulse length is RC seconds. Notice that the time is dependent completely, and solely, on the resistor and capacitor and is completely independent of VCC. **Figure 5** shows the signals of interest.

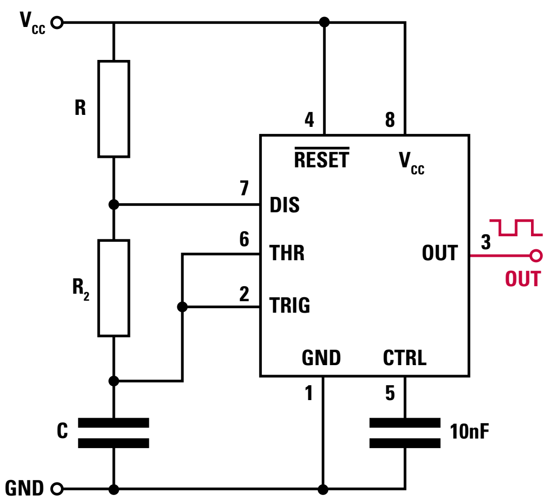


Figure 6
A 555 used in astable mode

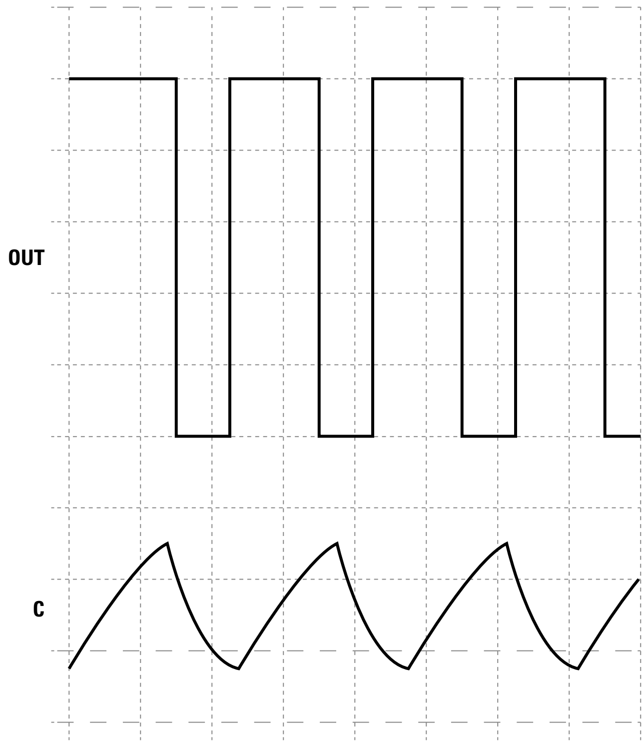


Figure 7
Significant signals in the astable circuit

ASTABLE

Astable means that the circuit doesn't have a stable state. It's continuously switching between them. **Figure 6** shows the basic circuit. There are two simple changes from **Figure 4**:

1. TRIG is connected to THRESH and the timing capacitor instead of being an external signal. This means that the 555 will be triggered when the voltage across C drops below 1/3 VCC. In the monostable configuration, when THRESH reached 2/3 VCC, C was immediately discharged (by the transistor connected to DISCH).

2. Since an alternating output is desired and immediate discharging would result in the 555 being triggered immediately, we need to slow the discharge. We can do that by adding another resistor (R2) between C and DISCH. C will then slowly discharge through R2, delaying the retriggering. This charge to 2/3 VCC, then discharge to 1/3 VCC cycle, will continue indefinitely, creating a square wave at OUT. Remember that OUT will be high when the capacitor is charging through both resistors, and low while it is discharging through R2. So the time it will be high is 0.693(R1 + R2)C seconds and it will be low for 0.693(R2)C. We have the expected RC products, but where did that 0.693 factor come from? That accounts for the voltage on C going between 1/3 VCC and 2/3 VCC rather than 0 V and 2/3 VCC. Note that the relationship between R1 and R2 determines the duty cycle of the output (that is, the relative time it is high vs. low) independent of C. Combined with C they determine the frequency. Also note that the duty cycle will be above 50% since C charges through R1+R2 but discharges through R2 alone. Attaining a 50% duty cycle would require R2 = R1+R2. That's not possible because when the discharge transistor was on, VCC would be connected to GND. This is generally considered a bad idea.

Figure 7 shows the important signals.

EXAMPLE CIRCUITS

Since the 555 has been around for so long, you can find projects using it in many places online and in books. The following are a handful of useful examples.

Mail alarm

We can use a 555 in bistable mode to monitor your mail slot. A switch on the mail slot's flapper is connected to TRIG. This could be a lever switch that is pushed by the flapper or a tilt switch mounted on the flapper. RESET is connected to another switch. If there's a lid on the mailbox, it could be connected to that, or it could be a manually activated push-button. In either case, it is pushed/closed when the mail is retrieved. OUT could be connected to a piezo buzzer or light. A buzzer is shown in **Figure 8** (overleaf). →

QUICK TIP

For some applications, a 555 or two can do as good or better of a job than a microcontroller and code.

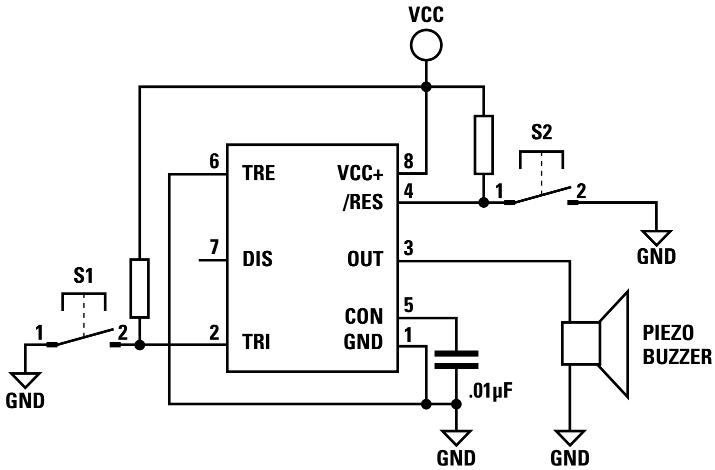


Figure 8
Mail alarm circuit

This could be done with a flip-flop IC, since that's what a 555 in bistable mode is. Using a 555 provides some benefit for a simple circuit like this, however. First, it's far more flexible in terms of power voltage. That means it can be directly battery powered. As the battery drains and its voltage decreases, the circuit will continue working until the voltage drops too low. Also, it only uses a single flip-flop. Flip-flop ICs are typically 14- or 16-pin chips containing at least two flip-flops. Contrast that with the 8-pin 555.

Toy organ

You can create a simple monophonic (one note at a time) toy organ by connecting a number of switches to select the frequency of a 555 in astable mode. You could use the switches to select one of the timing resistances, but that would affect the duty cycle (and thus the sound) as well as the frequency. A better approach is to use the switches to select between timing capacitors. This varies the overall frequency while keeping the duty cycle the same. As we saw earlier, duty cycle is only dependent on the resistors. See **Figure 9**. Capacitor values can be selected to generate desired frequencies:

.22 μF	52 Hz
.15 μF	78 Hz
.1 μF	111 Hz
.068 μF	170 Hz
.047 μF	230 Hz
.033 μF	348 Hz
.022 μF	490 Hz
.015 μF	718 Hz
.01 μF	1173 Hz
.0068 μF	1670 Hz
.0047 μF	2240 Hz

.0033 μF	3252 Hz
.0022 μF	4671 Hz
.0015 μF	6336 Hz
.001 μF	9237 Hz

Delayed signal

Sometimes you want an alert delayed a bit from the trigger event. To do this, you can use two 555s (or alternatively a 556). See **Figure 10** for the circuit. The first 555 is triggered by the external trigger signal. Its output will be a high pulse, whose length is determined by R and C. When it switches back to low, the second 555 is triggered, generating the required output signal pulse. OUT from the first 555 is coupled to the TRIG of the second through a capacitor with a pull-up resistor. This converts the change of OUT from high to low into a short low pulse for TRIG. The timing of the second 555 is set to generate the desired length of pulse.

A possible use for this circuit would be a tea timer. Trigger the first 555 when the water is poured, and have it set to delay for the steeping time required. You could use a rotary switch to select the timing resistor for different delays appropriate for different teas. Once that delay has completed, the second 555 turns on an indicator for some period of time. This could be a buzzer to alert you that your tea is ready.

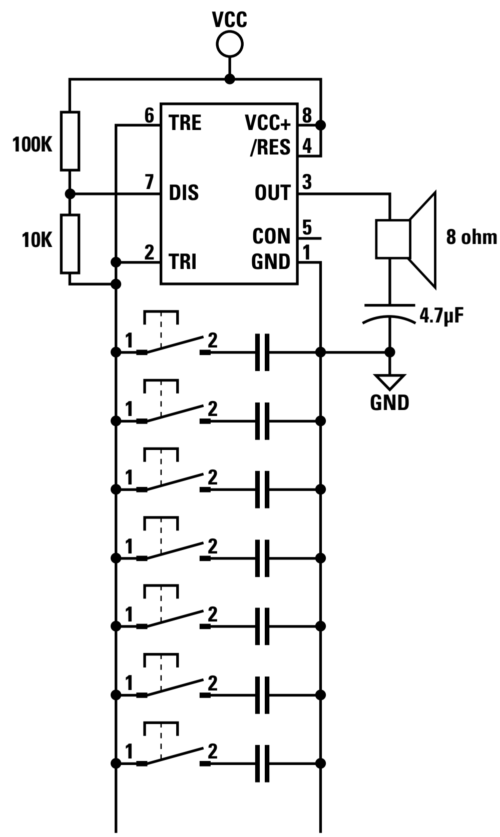
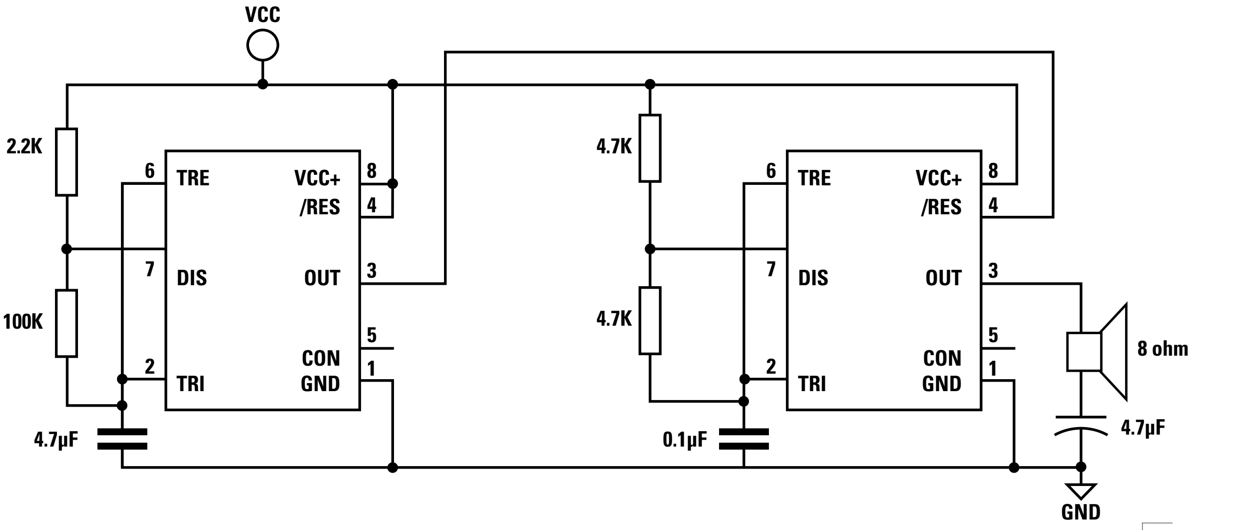


Figure 9
Toy organ circuit



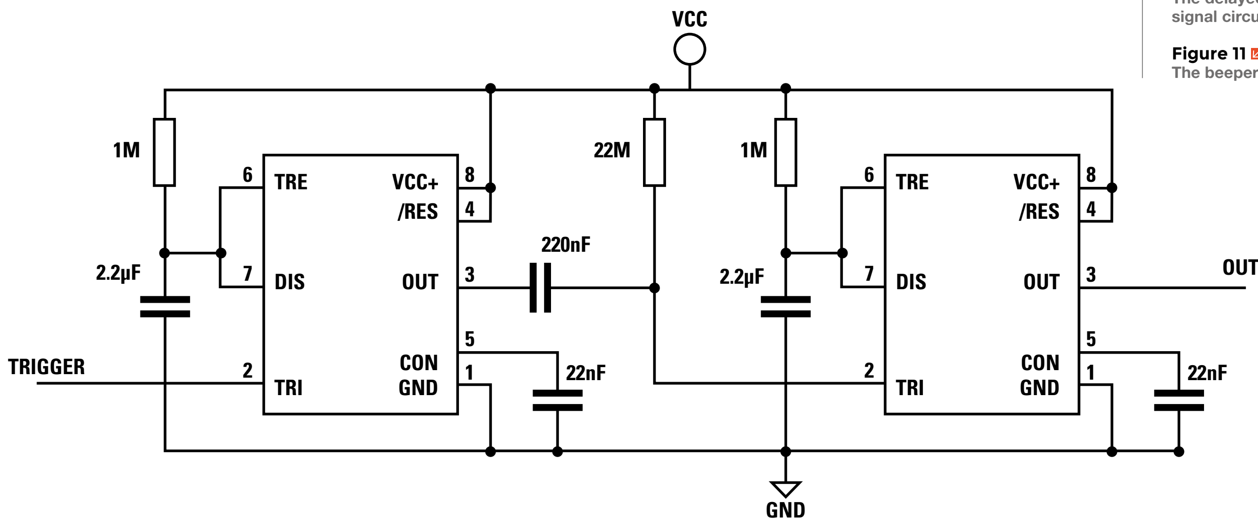


Figure 10 The delayed signal circuit

Figure 11 The beeper circuit

Beeper

We've seen how a 555 can generate a tone. We can use a second 555 to turn it into a beeper by using its OUT to control the RESET of the tone generator. **Figure 11** shows the circuit. When RESET is driven low (the stable state), the tone generator is disabled (quiet). When OUT takes RESET high, the tone generator operates. The result is a series of beeps. The pitch is determined by the second 555, while the interval and duration are set by the first.

Warbling tone generator

Instead of controlling the RESET of a tone generating 555 as above, we can use the OUT of the first 555 to provide additional current to the tone generator's timing capacitor, affecting how quickly it charges and thus the frequency of the tone. As the value of OUT changes, so will the tone's frequency (**Figure 12**, overleaf). →

LISTING 1

Arduino code for reading the pulse width

```
const int trigger = 8;
const int out = 9;

void setup() {
  Serial.begin(9600);
  pinMode(trigger, OUTPUT);
  digitalWrite(trigger, HIGH);
  pinMode(out, INPUT);
  delay(50);
  Serial.println("Starting");
}
```

```
void loop() {
  long count = 0;
  digitalWrite(trigger, LOW);
  digitalWrite(trigger, HIGH);
  while (digitalRead(out)) {
    count++;
  }
  Serial.println(count);
  delay(250);
}
```

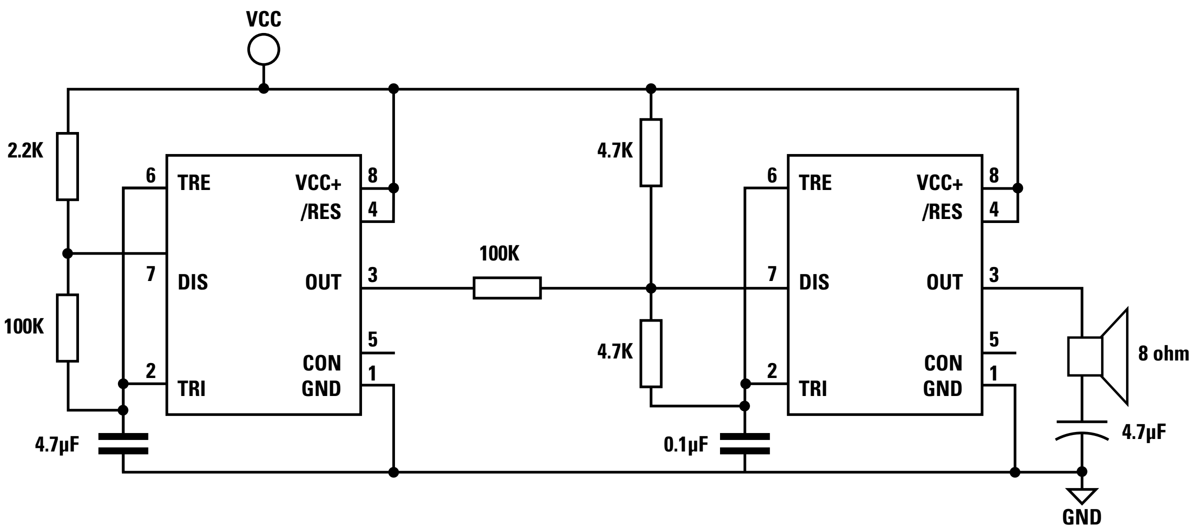


Figure 12 The warbling tone generator circuit

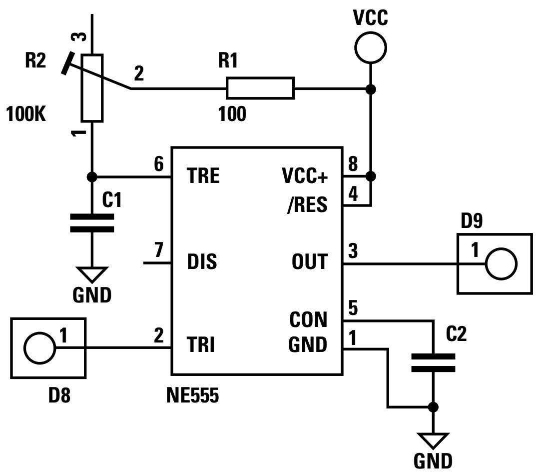


Figure 13 Circuit for reading a potentiometer position

GOING FURTHER

Here are some books and sites with more information and circuits:

- en.wikipedia.org/wiki/555_timer_IC
- *Mini Engineer's Notebook: 555 Timer IC Circuits* by Forrest M. Mims III (Radio Shack, 1984)
- *IC Timer Cookbook* by Walter G. Jung (Howard W. Sams & Co, Inc., 1977)
- *The Art of Electronics, 3rd Ed.* by Paul Horowitz and Winfield Hill (Cambridge University Press, 2015)
- *Practical Electronics for Inventors, 4th Ed.* by Paul Scherz and Simon Monk (McGraw Hill Education, 2016)

Above The 555

Potentiometer reader

The 555 was used in the Apple II family of computers to implement its joystick/paddle interface. Specifically the 558 chip, which contained four mostly independent 555s; some pins were shared to fit four of them onto a 16-pin chip. The circuits on the 558 were a derivative of the 555 that had reduced functionality, but work in monostable mode. The 558 is no longer in production and can be hard to find, so we'll build this for one potentiometer and use a 555. Since this uses software for measuring the pulse length, the ubiquitous Arduino Uno will be used.

The potentiometer is used as the timing resistor, which determines the length of the output pulse. It's read by triggering the timer and measuring how long the output is high. The length of a pulse is proportional to the value of the timing resistor, i.e. the position of the potentiometer. **Figure 13** shows the circuit, while Listing 1 shows the Arduino code.

We've looked at the 555's design and some examples of how it can be used, but that merely scratches the surface of what can be done. It's a chip that has been in production and use for close to 50 years. In that time, this little chip has been used and abused in a myriad of ways. It would take a series of books to discuss all of the applications to which it has been applied. Such a history for such a diminutive IC. □