Experiment #5—The Integrated Timer

Background

Timer circuits based on the 555 chip and its many relatives are found everywhere. Although not complex, it can be used to create many different circuits. This month we'll take a look at two popular applications of the legendary 555.

Terms to Learn

- *Astable*—not stable; a circuit that cannot stay in one state.
- *Comparator*—a circuit whose output is indicative of the greater of two of its inputs.
- *Flip-flop*—a digital circuit that "flips" or "toggles" between two states.
- *Monostable*—stable in one state, these circuits stay there until perturbed, then attempt to return to the stable state.

The Integrated Circuit Timer

The 555 integrated circuit timer has proved to be incredibly popular. Inexpensive and versatile, the 555 is used in myriads of circuits. What's inside that makes it so useful?

Figure 1 shows the basic components of a 555. While it is the most complex circuit we've looked at so far, the 555 is easy to break into bite-size pieces. Let's start with the three resistors labeled "R" at the top left of Figure 1. Connected between power input (V_{cc}) and ground, they form a *voltage divider* that divides V_{cc} into two equal steps—one at $^2/_3$ V_{cc} and one at $^1/_3$ V_{cc}. These serve as reference voltages.

Connected to the reference voltages are blocks labeled *trigger comparator* and *threshold comparator*. A *comparator* is nothing more than a circuit whose output indicates which of its two inputs is greater. If the + input is greater, the output is *high*. If the – input is greater, the output is at ground or *low*.

The trigger comparator in the 555 is wired so that its output is *high* whenever the trigger input is *less* than $^1/_3$ V_{cc} and vice versa. Similarly, the threshold comparator output is *high* whenever the threshold input is *greater* than $^2/_3$ V_{cc}. These two outputs control a circuit called a *flip-flop*.

The flip-flop output, *Q*, changes to *high* or *low* when the state of its *set* and *reset* input changes. The Q output stays *high* or *low* (it *latches* or *toggles*) until the opposite input changes. When the set input changes from *low* to *high*, Q goes *high*. When reset changes from *low* to *high*, Q goes *low*. The flip-flop ignores any other changes. An inverter makes the 555 output *high* when Q is *low* and vice versa—this makes the timer circuit easier to interface with external circuits.

The transistor connected to Q acts as a *switch*. When Q is *high*, the transistor is *on* and acts as a closed switch connected to ground. When Q is *low*, the transistor is *off* and the switch is open. These simple building blocks—*voltage divider*, *comparator*, *flip-flop* and *switch*—allow us to build a surprising number of useful circuits.

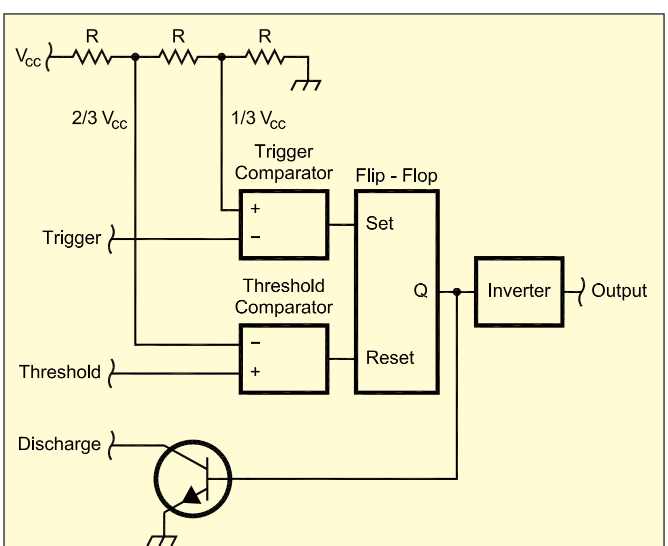

Figure 1—This schematic shows the major circuits inside the 555 timer.

The Monostable or "One-Shot" Multivibrator

The simplest 555 circuit is the *monostable* circuit. This configuration will output one fixed-length pulse when triggered by an input pulse. Figure 2 shows the connections for this circuit. How does it work?

Starting with capacitor C discharged, the flip-flop output, Q, is *high*, which keeps the discharge transistor turned on and the voltage across C below $^2/_3$ V_{cc}. The circuit is in its stable state, waiting for a trigger pulse.

When the voltage at the trigger input drops below $^1/_3$ V_{cc}, the trigger comparator output changes from *low* to *high*, which causes Q to toggle to the *low* state. This turns *off* the transistor (opens the switch) and allows C to begin charging toward V_{cc}.

When C reaches $^2/_3$ V_{cc}, the threshold comparator switches its output from *low* to *high* and that resets the flip-flop. Q returns *high*, turning *on* the transistor and discharging C. The circuit has returned to its stable state. The output pulse length is:

$$T = 1.1\ RC \qquad [1]$$

Notice that V_{cc} doesn't really matter in the timing—the out-

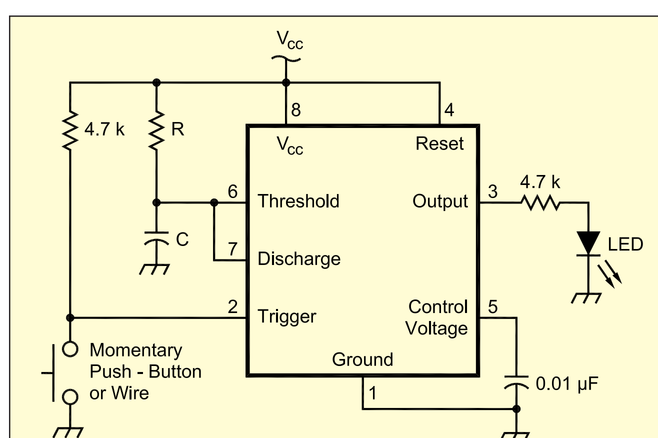

Figure 2—The monostable or "one-shot" circuit. This circuit generates a single pulse when the trigger input is shorted to ground. An LED is used to indicate whether the output is high or low.

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put pulse width is the same with a 5 V supply as it is with a 15 V supply. This is because the 555 design is based on ratios and not absolute voltage levels.

Testing the Monostable Multivibrator

- Use the wiring diagram of Figure 2. Let's aim for a 1 second output pulse, which requires RC = 1/1.1 = 0.91. If we choose C = 10 µF, then R = 91 kΩ.
- Connect a 4.7 kΩ resistor between V_{cc} and pin 2. The symbol at pin 2 indicates a jumper to ground—you can use a switch or a piece of wire to temporarily ground pin 2, supplying the trigger pulse.
- The 4.7 kΩ resistor and LED at the output will give a visual indication when the output is *high*.
- The 0.01 µF capacitor at pin 5 filters out any noise that might cause changes in the threshold comparator reference voltage. Pin 4 resets the flip-flop that drives the output and it can be used to prematurely force the output low, regardless of the output state. It should be connected to V_{cc} when not used, to prevent resets from noise. The power supply voltage can be any positive voltage between 4.5 and 18 V.
- With your circuit ready to go, press the switch (or insert the jumper for a brief instant) and watch the output LED light up. It should be on for about 1 second and then turn off until you retrigger the circuit.
- Change either R or C, recalculate the expected output pulse length, and give it a try. R can be a potentiometer, as well, for adjustable pulse length.

The Astable Multivibrator

The opposite of the monostable circuit is the astable circuit in Figure 3. Look carefully at the different connections of pins 2, 6 and 7. Notice, too, that the timing resistor is split into two resistors, R1 and R2. What's happening here?

Let's start from the same state as the monostable circuit, with C completely discharged. In the monostable circuit, it took a trigger signal to get the ball rolling. In the astable circuit, the trigger input is connected directly to the capacitor, so if the capacitor is discharged, then the trigger comparator output must be *high*. Q is *low*, turning *off* the discharge transistor, which allows C to immediately begin charging.

C charges toward V_{cc}, but now through the combination of R1 and R2. As the capacitor voltage passes $\frac{2}{3}$ V_{cc}, the threshold comparator output changes from *low* to *high*, resetting Q to *high*. This turns *on* the discharge transistor and the capacitor starts to discharge through R2. When the capacitor is discharged below $\frac{1}{3}$ V_{cc}, the trigger comparator changes from *high* to *low* and the cycle begins again, automatically. This happens over and over, causing a train of pulses at the output while C charges and discharges between $\frac{1}{3}$ and $\frac{2}{3}$ V_{cc} as shown in Figure 4.

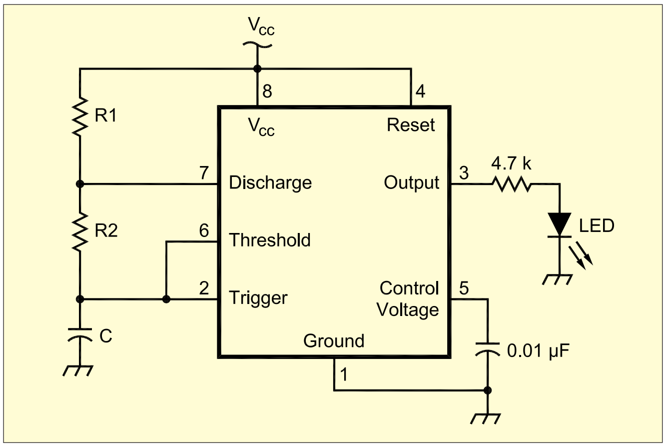

Figure 3—The astable or "free-running" circuit. This circuit generates a continuous train of output pulses.

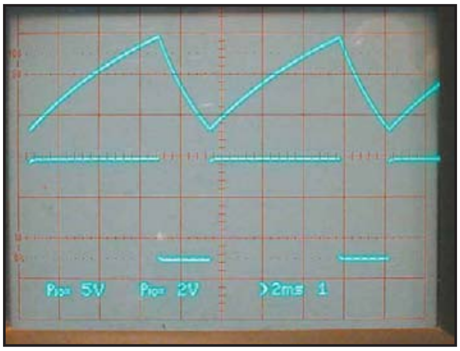

Figure 4—A photo of the oscilloscope showing the capacitor and output voltages for the astable circuit with a 0.1 µF timing capacitor for a 100 Hz oscillation frequency. The top trace shows capacitor voltage and the bottom trace the 555 output. Capacitor charging and discharging can be seen clearly.

The design equations are a little more complex for this circuit. The total time it takes for one complete cycle is the charge time, T_c, plus the discharge time, T_d:

$$T = T_c + T_d = 0.693\,(R_1 + R_2)\,C + 0.693\,R_2C$$

$$= 0.693\,(R_1 + 2R_2)\,C \qquad [2]$$

and the output frequency is:

$$f = 1/T = 1.443 / [(R_1 + 2R_2)\,C] \qquad [3]$$

Let's try it out!

Testing the Astable Multivibrator

- Split the original 91 kΩ resistor into a 62 kΩ for R1 and 39 kΩ for R2. Use the same 10 µF capacitor for C. The total cycle time should be close to 1 second. If you have a stopwatch, count 10 or more cycles and average for a good cycle time measurement.
- You may have noted that the LED is not on and off for equal periods—it's on longer than it is off. This is because the capacitor has to both charge and discharge through R_2. The ratio of on-time to off-time is called the *duty cycle* and is calculated as:

$$\text{duty cycle} = (R_1 + R_2) / (R_1 + 2R_2) \qquad [4]$$

- Experiment with different combinations of R1 and R2 to observe the effect of their ratio on duty cycle. (Keep R1 greater than 1 kΩ to avoid overloading the discharge transistor.) If you have an oscilloscope, watch the capacitor voltage on one channel and the output voltage on the other. Figure 4 shows an example.

Suggested Reading

Read *The ARRL Handbook*, chapter 7, page 7.14, specifically the paragraphs starting with "Multivibrators" and the section "RC Time Constant" in chapter 6. Additionally, see *The Art of Electronics*, pages 517-522. One of the better on-line 555 application notes is **www.doctronics.co.uk/pdf_files/555an.pdf**. If you can, find a copy of Walter Jung's *IC Timer Cookbook* or Howard Berlin's *555 Timer Applications Sourcebook.* Both are excellent, although now out of print. And, remember… the ARRL Web site for this series is **www.arrl.org/tis/info/html/Hands-On-Radio/**.

Shopping List

- 555 timer IC (RadioShack 276-1723).
- 10 µF and 10 nF capacitors.
- 4.7 kΩ (2), 39 kΩ, 62 kΩ, 91 kΩ resistors, ¼ W.

Next Month

Another popular well-designed integrated device is the linear regulator. It is so easy to use that we tend to take it for granted. When you use a power supply, it's likely that one of these is integral to its design. See you next month!