Experiment 16: Emitting a Pulse

I'm going to introduce you to the most successful chip ever made: the 555 timer. As you can find numerous guides to it online, you might question the need to discuss it here, but I have three reasons for doing so:

1. It's unavoidable. You simply have to know about this chip. Some sources estimate that more than 1 billion are still being manufactured annually. It will be used in one way or another in most of the remaining circuits in this book.
2. It provides a perfect introduction to integrated circuits, because it's robust, versatile, and illustrates two functions that we'll be dealing with later: comparators and a flip-flop.
3. After reading all the guides to the 555 that I could find, beginning with the original Fairchild Semiconductor data sheet and making my way through various hobby texts, I concluded that its inner workings are seldom explained very clearly. I want to give you a graphic understanding of what's happening inside it, because if you don't have this, you won't be in a good position to use the chip creatively.

You will need:

- 9-volt power supply.
- Breadboard, jumper wires, and multimeter.
- 5K linear potentiometer. Quantity: 1.
- 555 timer chip. Quantity: 1.
- Assorted resistors and capacitors.
- SPST tactile switches. Quantity: 2.
- LED (any type). Quantity: 1.

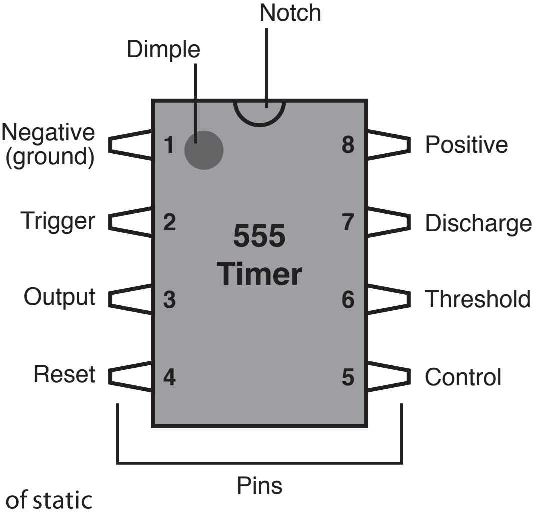

Figure 4-13. *The 555 timer chip, seen from above. Pins on chips are always numbered counterclockwise, from the top-left corner, with a notch in the body of the chip uppermost, or a circular indentation at top-left, to remind you which end is up.*

Procedure

The 555 chip is very robust, but still, in theory, you can zap it with a jolt of static electricity and kill it. Therefore, to be on the safe side, you should ground yourself before handling it. See the "Grounding yourself" warning on page 172 for details. Although this warning primarily refers to the type of chips known as CMOS, which are especially vulnerable, grounding yourself is always a sensible precaution.

Look for a small circular indentation, called the *dimple*, molded into the body of the chip, and turn the chip so that the indentation is at the top-left corner with the pins pointing down. Alternatively, if your chip is of the type with a notch at one end, turn the chip so that the notch is at the top.

The pins on chips are always numbered counterclockwise, starting from the top-left pin (next to the dimple). See Figure 4-13, which also shows the names of the pins on the 555 timer, although you don't need to know most of them just yet.

Insert the chip in your breadboard so that its pins straddle the channel down the center. Now you can easily feed voltages to the pins on either side, and read signals out of them. See Figure 4-14 for a precise guide to placement, in the first project. The timer is identified as "IC1," because "IC" is the customary abbreviation for "Integrated Circuit."

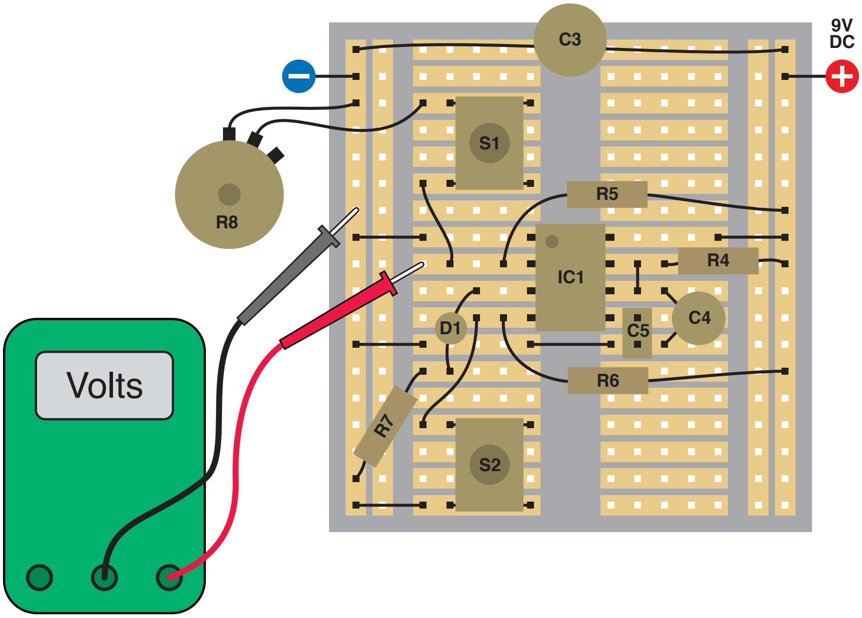

Figure 4-14. *This circuit allows you to explore the behavior of the 555 timer chip. Use your meter to monitor the voltage on pin 2 as shown. There are no resistors labeled R1, R2, or R3 and no capacitors labeled C1 or C2, because they'll be added in a later schematic. Component values in this schematic:*

R4: 100K
R5: 2K2
R6: 10K
R7: 1K
R8: 5K linear potentiometer
C3: 100 µF electrolytic
C4: 47 µF electrolytic
C5: 0.1 µF ceramic
IC1: 555 timer
S1, S2: SPST tactile switches (pushbuttons)
D1: Generic LED

R5 holds the trigger (pin 2) positive until S1 is pressed, which lowers the voltage depending on the setting of potentiometer R8. When the trigger voltage falls below 1/3 of the power supply, the chip's output (pin 3) goes high for a period determined by the values of R4 and C4. S2 resets (zeros) the timer, by reducing the voltage to pin 4, the Reset. C3 smoothes the power supply, and C5 isolates pin 5, the control, so that it won't interfere with the functioning of this test circuit. (We'll use the control pin in a future experiment.)

All integrated circuit chips require a power supply. The 555 is powered with negative voltage applied to pin 1 and positive to pin 8. If you reverse the voltage accidentally, this can permanently damage the chip, so place your jumper wires carefully.

Set your power supply to deliver 9 volts. It will be convenient for this experiment if you supply positive down the righthand side and negative down the lefthand side of the breadboard, as suggested in Figure 4-14. C3 is a large capacitor, at least 100 µF, which is placed across the power supply to smooth it out and provide a local store of charge to fuel fast-switching circuits, as well as to guard against other transient dips in voltage. Although the 555 isn't especially fast-switching, other chips are, and you should get into the habit of protecting them.

Begin with the potentiometer turned all the way counterclockwise to maximize the resistance between the two terminals that we're using, and when you apply the probe from your meter to pin 2, you should measure about 6 volts when you press S1.

Now rotate the potentiometer clockwise and press S1 again. If the LED doesn't light up, keep turning the potentiometer and pressing and releasing the button. When you've turned the potentiometer about two-thirds of the way, you should see the LED light up for just over 5 seconds when you press and release the button. Here are some facts that you should check for yourself:

- The LED will keep glowing after you release the button.
- You can press the button for any length of time (less than the timer's cycle time) and the LED always emits the same length of pulse.
- The timer is triggered by a fall in voltage on pin 2. You can verify this with your meter.
- The LED is either fully on or fully off. You can't see a faint glow when it's off, and the transition from off to on and on to off is very clean and precise.

Check Figure 4-16 to see how the components should look on your breadboard, and then look at the schematic in Figure 4-15 to understand what's happening. I will be adding more components later, which I will be labeling R1, R2, C1, and C2 to be consistent with data sheets that you may see for the 555 timer. Therefore, in this initial circuit the resistors are labeled R4 and up, and capacitors C3 and up.

When S1 (the tactile switch) is open, pin 2 of the 555 timer receives positive power through R5, which is 2K2. Because the input resistance of the timer is very high, the voltage on pin 2 is almost the full 9 volts.

When you press the button, it connects negative voltage through R8, the 5K potentiometer to pin 2. Thus, R8 and R5 form a voltage divider with pin 2 in the middle. You may remember this concept from when you were testing transistors. The voltage between the resistances will change, depending on the values of the resistances.

If R8 is turned up about halfway, it is approximately equal to R5, so the midpoint, connected to pin 2, has about half the 9-volt power supply. But when you turn the potentiometer so that its resistance falls farther, the negative voltage outweighs the positive voltage, so the voltage on pin 2 gradually drops.

If you have clips on your meter leads, you can hook them onto the nearest jumper wires and then watch the meter while you turn the potentiometer up and down and press the button.

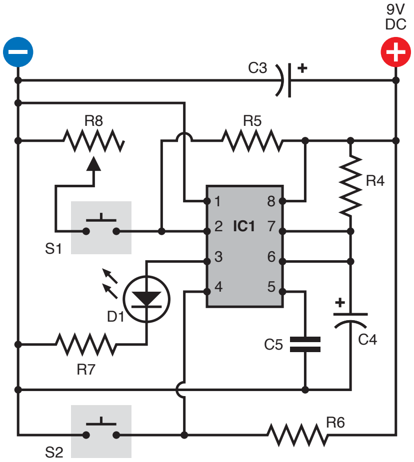

Figure 4-15. *A schematic view of the circuit shown in Figure 4-14. Throughout this chapter, the schematics will be laid out to emulate the most likely placement of components on a breadboard. This is not always the simplest layout, but will be easiest for you to build. Refer to Figure 4-14 for the values of the components.*

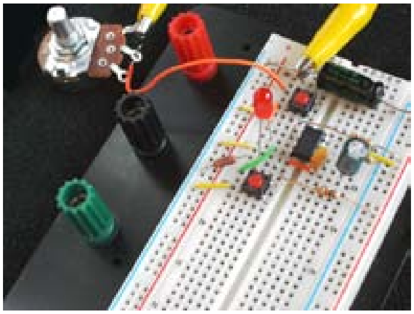

Figure 4-16. *This is how the components look when installed on the breadboard. The alligator clips are attached to a patch cord that links the 100 µF capacitor to the potentiometer. The power supply input is not shown.*

The graphs in Figure 4-17 illustrate what is happening. The upper graph shows the voltage applied to pin 2 by random button-presses, with the potentiometer turned to various values. The lower graph shows that the 555 is triggered if, and only if, the voltage on pin 2 actively drops from above 3 volts to below 3 volts. What's so special about 3 volts? It's one-third of our 9-volt power supply.

Here's the take-home message:

- The output of the 555 (pin 3) emits a *positive* pulse when the trigger (pin 2) drops *below* one-third of the supply voltage.
- The 555 delivers the *same duration* of positive pulse every time (so long as you don't supply a prolonged low voltage on pin 2).
- A *larger* value for R4 or for C4 will *lengthen* the pulse.
- When the output (pin 3) is high, the voltage is almost equal to the supply voltage. When the output goes low, it's almost zero.

The 555 converts the imperfect world around it into a precise and dependable output. It doesn't switch on and off absolutely instantly, but is fast enough to *appear* instant.

Now here's another thing to try. Trigger the timer so that the LED lights up. While it is illuminated, press S2, the second button, which grounds pin 4, the reset. The LED should go out immediately.

When the reset voltage is pulled *low*, the output goes *low*, regardless of what voltage you apply to the trigger.

There's one other thing I want you to notice before we start using the timer for more interesting purposes. I included R5 and R6 so that when you first switch on the timer, it is not emitting a pulse—but is ready to do so. These resistors apply a positive voltage to the trigger and the reset pin, to make sure that the 555 timer is ready to run when you first apply power to it.

As long as the *trigger* voltage is *high*, the timer *will not* emit a pulse. (It emits a pulse when the trigger voltage drops.)

As long as the *reset* voltage is *high*, the timer is *able* to emit a pulse. (It shuts down when the reset voltage drops.)

R5 and R6 are known as "pull-up resistors" because they pull the voltage up. You can easily overwhelm them by adding a direct connection to the negative side of the power supply. A typical pull-up resistor for the 555 timer is 10K. With a 9-volt power supply, it only passes 0.9mA (by Ohm's Law).

Finally, you may be wondering about the purpose of C5, attached to pin 5. This pin is known the "control" pin, which means that if you apply a voltage to it, you can control the sensitivity of the timer. I'll get to this in more detail a little later. Because we are not using this function right now, it's good practice to put a capacitor on pin 5 to protect it from voltage fluctuations and prevent it from interfering with normal functioning.

Make sure you become familiar with the basic functioning of the 555 timer before you continue.

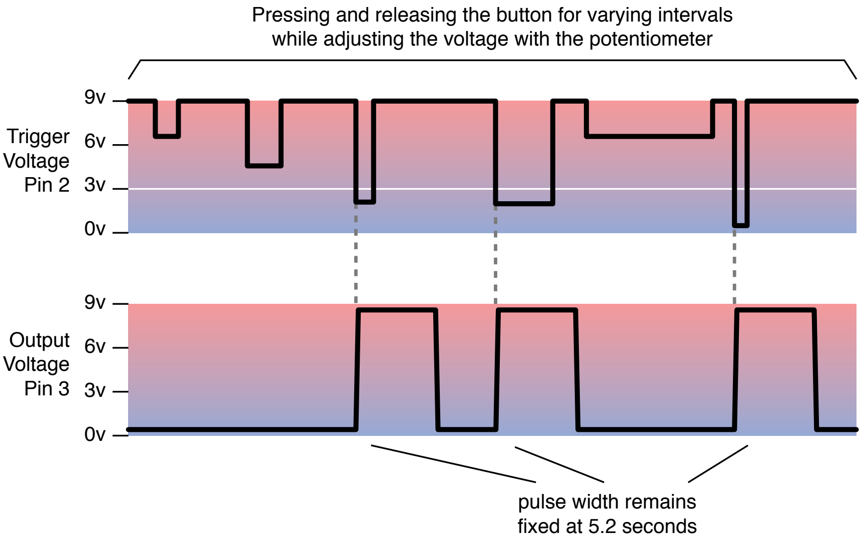

Figure 4-17. *The top graph shows voltage on the trigger (pin 2) when the pushbutton is pressed, for different intervals, at different settings of the potentiometer. The lower graph shows the output (pin 3), which rises until it is almost equal to the power supply, when the voltage on pin 2 drops below 1/3 the full supply voltage.*

FUNDAMENTALS

The following table shows 555 pulse duration in monostable mode:

- Duration is in seconds, rounded to two figures.
- The horizontal scale shows common resistor values between pin 7 and positive supply voltage.
- The vertical scale shows common capacitor values between pin 6 and negative supply voltage.

To calculate a different pulse duration, multiply resistance × capacitance × 0.0011 where resistance is in kilohms, capacitance is in microfarads, and duration is in seconds.

	1K	2K2	4K7	10K	22K	47K	100K	220K	470K	1M
47 µF	0.05	0.11	0.24	0.52	1.1	2.4	5.2	11	24	52
22 µF	0.02	0.05	0.11	0.24	0.53	1.1	2.4	5.3	11	24
10 µF	0.01	0.02	0.05	0.11	0.24	0.52	1.1	2.4	5.2	11
4.7 µF		0.01	0.02	0.05	0.11	0.24	0.52	1.1	2.4	5.2
2.2 µF			0.01	0.02	0.05	0.11	0.24	0.53	1.1	2.4
1.0 µF				0.01	0.02	0.05	0.11	0.24	0.52	1.1
0.47 µF					0.01	0.02	0.05	0.11	0.24	0.52
0.22 µF						0.01	0.02	0.05	0.11	0.24
0.1 µF							0.01	0.02	0.05	0.11
0.047 µF								0.01	0.02	0.05
0.022 µF									0.01	0.02
0.01 µF										0.01

THEORY

Inside the 555 timer: monostable mode

The plastic body of the 555 timer contains a wafer of silicon on which are etched dozens of transistor junctions in a pattern that is far too complex to be explained here. However, I can summarize their function by dividing them into groups, as shown in Figure 4-18. An external resistor and two external capacitors are also shown, labeled the same way as in Figure 4-15.

The negative and positive symbols inside the chip are power sources which actually come from pins 1 and 8, respectively. I omitted the internal connections to those pins for the sake of clarity.

The two yellow triangles are "comparators." Each comparator compares two inputs (at the base of the triangle) and delivers an output (from the apex of the triangle) depending on whether the inputs are similar or different. We'll be using comparators for other purposes later in this book.

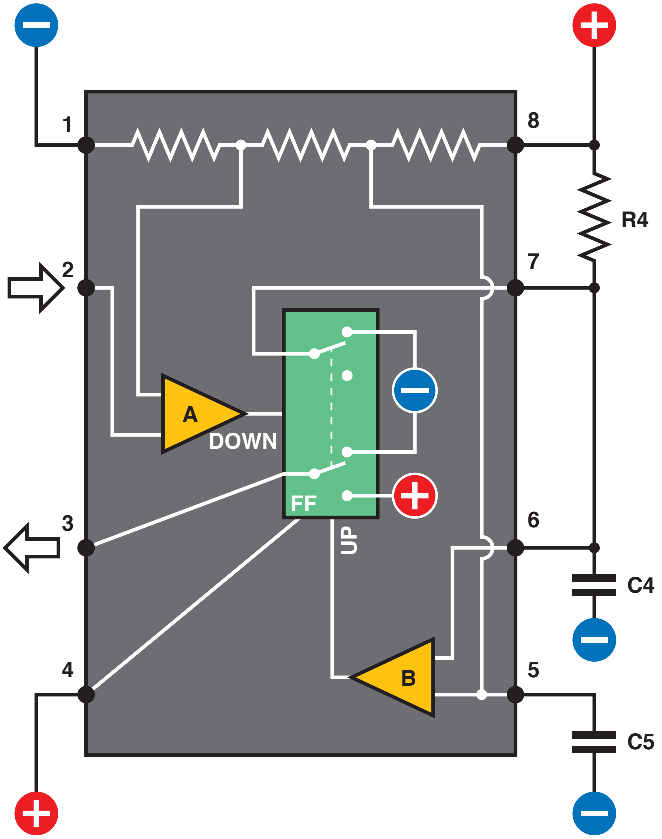

Figure 4-18. *Inside the 555 timer. White lines indicate connections inside the chip. A and B are comparators. FF is a flip-flop which can rest in one state or the other, like a double-throw switch. A drop in voltage on pin 2 is detected by comparator A, which triggers the flip-flop into its "down" position and sends a positive pulse out of pin 3. When C4 charges to 2/3 of supply voltage, this is detected by comparator B, which resets the flip-flop to its "up" position. This discharges C4 through pin 7.*

THEORY

Inside the 555 timer: monostable mode (continued)

The green rectangle, identified as "FF," is a "flip-flop." I have depicted it as a DPDT switch, because that's how it functions here, although of course it is really solid-state.

Initially when you power up the chip, the flip-flop is in its "up" position which delivers low voltage through the output, pin 3. If the flip-flop receives a signal from comparator A, it flips to its "down" state, and flops there. When it receives a signal from comparator B, it flips back to its "up" state, and flops there. The "UP" and "DOWN" labels on the comparators will remind you what each one does when it is activated.

Flip-flops are a fundamental concept in digital electronics. Computers couldn't function without them.

Notice the external wire that connects pin 7 with capacitor C4. As long as the flip-flop is "up," it sinks the positive voltage coming through R4 and prevents the capacitor from charging positively.

If the voltage on pin 2 drops to 1/3 of the supply, comparator A notices this, and flips the flip-flop. This sends a positive pulse out of pin 3, and also disconnects the negative power through pin 7. So now C4 can start charging through R4. While this is happening, the positive output from the timer continues.

As the voltage increases on the capacitor, comparator B monitors it through pin 6, known as the threshold. When the capacitor accumulates 2/3 of the supply voltage, comparator B sends a pulse to the flip-flop, flipping it back into its original state. This discharges the capacitor through pin 7, appropriately known as the discharge pin. Also, the flip-flop ends the positive output through pin 3 and replaces it with a negative voltage. This way, the 555 returns to its original state.

I'll sum up this sequence of events very simply:

1. Initially, the flip-flop grounds the capacitor and grounds the output (pin 3).
2. A drop in voltage on pin 2 to 1/3 the supply voltage or less makes the output (pin 3) positive and allows capacitor C4 to start charging through R4.
3. When the capacitor reaches 2/3 of supply voltage, the chip discharges the capacitor, and the output at pin 3 goes low again.

In this mode, the 555 timer is "monostable," meaning that it just gives one pulse, and you have to trigger it again to get another.

You adjust the length of each pulse by changing the values of R4 and C4. How do you know which values to choose? Check the table on page 157, which gives an approximate idea and also includes a formula so that you can calculate values of your own.

I didn't bother to include pulses shorter than 0.01 second in the table, because a single pulse of this length is usually not very useful. Also I rounded the numbers in the table to 2 significant figures, because capacitor values are seldom more accurate than that.

BACKGROUND

How the timer was born

Back in 1970, when barely a half-dozen corporate seedlings had taken root in the fertile ground of Silicon Valley, a company named Signetics bought an idea from an engineer named Hans Camenzind. It wasn't a huge breakthrough concept—just 23 transistors and a bunch of resistors that would function as a programmable timer. The timer would be versatile, stable, and simple, but these virtues paled in comparison to its primary selling point. Using the emerging technology of integrated circuits, Signetics could reproduce the whole thing on a silicon chip.

This entailed some trial and error. Camenzind worked alone, building the whole thing initially on a large scale, using off-the-shelf transistors, resistors, and diodes on a breadboard. It worked, so then he started substituting slightly different values for the various components to see whether the circuit would tolerate variations during production and other factors such as changes in temperature when the chip was in use. He made at least 10 different versions of the circuit. It took months.

Next came the crafts work. Camenzind sat at a drafting table and used a specially mounted X-Acto knife to scribe his circuit into a large sheet of plastic. Signetics then reduced this image photographically by a ratio of about 300:1. They etched it into tiny wafers, and embedded each of them in a half-inch rectangle of black plastic with the product number printed on top. Thus, the 555 timer was born.

It turned out to be the most successful chip in history, both in the number of units sold (tens of billions and counting) and the longevity of its design (unchanged in almost 40 years). The 555 has been used in everything from toys to spacecraft. It can make lights flash, activate alarm systems, put spaces between beeps, and create the beeps themselves.

Today, chips are designed by large teams and tested by simulating their behavior using computer software. Thus, chips inside a computer enable the design of more chips. The heyday of solo designers such as Hans Camenzind is long gone, but his genius lives inside every 555 timer that emerges from a fabrication facility. (If you'd like to know more about chip history, see *http://www.semiconductormuseum.com/Museum_Index.htm*.)

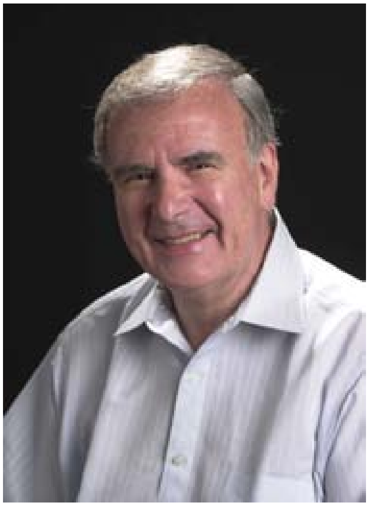

Figure 4-13. *Hans Camenzind, inventor and developer of the 555 timer chip for Signetics.*

FUNDAMENTALS

Why the 555 is useful

In its monostable mode (which is what you just saw), the 555 will emit a single pulse of fixed (but programmable) length. Can you imagine some applications? Think in terms of the pulse from the 555 controlling some other component. A motion sensor on an outdoor light, perhaps. When an infra-red detector "sees" something moving, the light comes on for a specific period—which can be controlled by a 555.

Another application could be a toaster. When someone lowers a slice of bread, a switch will close that triggers the toasting cycle. To change the length of the cycle, you could use a potentiometer instead of R4 and attach it to the external lever that determines how dark you want your toast. At the end of the toasting cycle, the output from the 555 would pass through a power transistor, to activate a solenoid (which is like a relay, except that it has no switch contacts) to release the toast.

Intermittent windshield wipers could be controlled by a 555 timer—and on earlier models of cars, they actually were.

And what about the burglar alarm that was described at the end of Chapter 3? One of the features that I listed, which has not been implemented yet, is that it should shut itself off after a fixed interval. We can use the change of output from a 555 timer to do that.

The experiment that you just performed seemed trivial, but really it implies all kinds of possibilities.

555 timer limits

1. The timer can run from a stable voltage source ranging from 5 to 15 volts.
2. Most manufacturers recommend a range from 1K to 1M for the resistor attached to pin 7.
3. The capacitor value can go as high as you like, if you want to time really long intervals, but the accuracy of the timer will diminish.
4. The output can deliver as much as 100mA at 9 volts. This is sufficient for a small relay or miniature loudspeaker, as you'll see in the next experiment.

Beware of Pin-Shuffling!

In all of the schematics in this book, I'll show chips as you'd see them from above, with pin 1 at top left. Other schematics that you may see, on websites or in other books, may do things differently. For convenience in drawing circuits, people shuffle the pin numbers on a chip so that pin 1 isn't necessarily shown adjacent to pin 2.

Look at the schematic in Figure 4-20 and compare it with the one in Figure 4-15. The connections are the same, but the one in Figure 4-20 groups pins to reduce the apparent complexity of the wiring.

"Pin shuffling" is common because circuit-drawing software tends to do it, and on larger chips, it is necessary for functional clarity of the schematic (i.e., logical groupings of pin names versus physical groupings on memory chips, for example). When you're first learning to use chips, I think it's easier to understand a schematic that shows the pins in their actual positions. So that's the practice I will be using here.

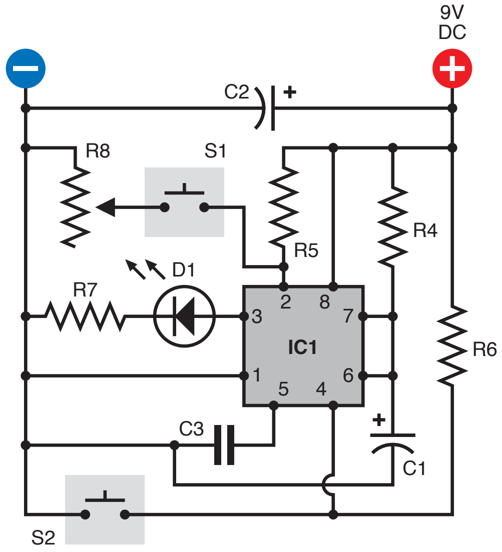

Figure 4-20. *Many people draw schematics in which the pin numbers on a chip are shuffled around to make the schematic smaller or simpler. This is not helpful when you try to build the circuit. The schematic here is for the same circuit as in Figure 4-15. This version would be harder to recreate on a breadboard.*

Experiment 17: Set Your Tone

I'm going to show you two other ways in which the 555 timer can be used.

You will need the same items as in Experiment 16, plus:

- Additional 555 timer chip. Quantity: 1.
- Miniature loudspeaker. Quantity: 1.
- 100K linear potentiometer. Quantity: 1.

Procedure

Leave the components from Experiment 16 where they are on the breadboard, and add the next section below them, as shown in Figures 4-21 and 4-22. Resistor R2 is inserted between pins 6 and 7, instead of the jumper wire that shorted the pins together in the previous circuit, and there's no external input to pin 2 anymore. Instead, pin 2 is connected via a jumper wire to pin 6. The easiest way to do this is by running the wire across the top of the chip.

I have omitted the smoothing capacitor from the schematic in Figure 4-22, because I'm assuming that you're running this circuit on the same breadboard as the first, where the previous smoothing capacitor is still active.

A loudspeaker in series with a 100Ω resistor (R3) has been substituted for the LED to show the output from the chip. Pin 4, the reset, is disabled by connecting it to the positive voltage supply, as I'm not expecting to use the reset function in this circuit.

Now what happens when you apply power? Immediately, you should hear noise through the loudspeaker. If you don't hear anything, you almost certainly made a wiring error.

Notice that you don't have to trigger the chip with a pushbutton anymore. The reason is that when C1 charges and discharges, its fluctuating voltage is connected via a jumper wire across the top of the chip to pin 2, the trigger. In this way, the 555 timer now triggers itself. I'll describe this in more detail in the next section "Theory: Inside the 555 timer: astable mode," if you want to see exactly what is going on.

In this mode, the chip is "astable," meaning that it is not stable, because it flips to and fro endlessly, sending a stream of pulses for as long as the power is connected. The pulses are so rapid that the loudspeaker reproduces them as noise.

In fact, with the component values that I specified for R1, R2, and C1, the 555 chip is emitting about 1,500 pulses per second. In other words, it creates a 1.5 KHz tone.

Check the table on page 166 to see how different values for R2 and C1 can create different pulse frequencies with the chip in this astable mode. Note that the table assumes a fixed value of 1K for R1!

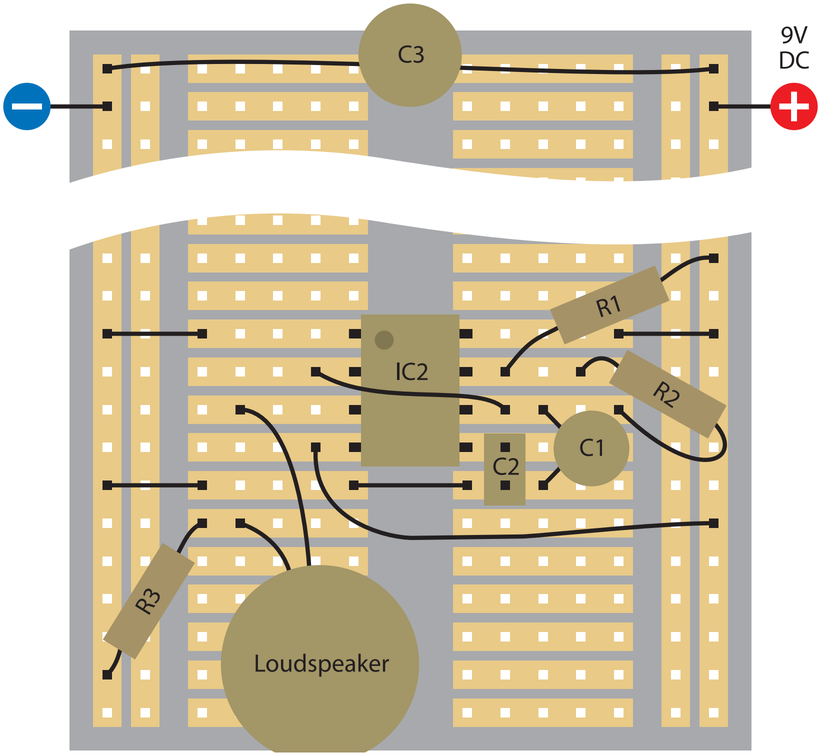

Figure 4-21. *These components should be added on the same breadboard below the components shown in Figure 4-14. Use the following values to test the 555 timer in its astable mode:*

R1: 1K
R2: 10K
R3: 100Ω
C1: 0.047 µF ceramic or electrolytic
C2: 0.1 µF ceramic
IC2: 555 timer

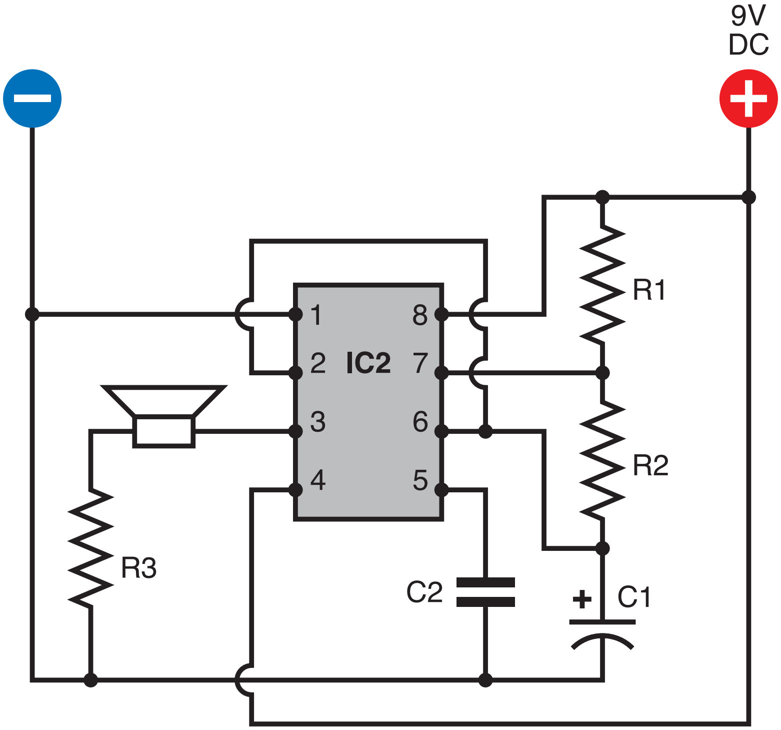

Figure 4-22. *This is the schematic version of the circuit shown in Figure 4-21. The component values are the same.*

THEORY

Inside the 555 timer: astable mode

Here's what is happening now, illustrated in Figure 4-23. Initially, the flip-flop grounds C1 as before. But now the low voltage on the capacitor is connected from pin 7 to pin 2 through an external wire. The low voltage tells the chip to trigger itself. The flip-flop obediently flips to its "on" position and sends a positive pulse to the loudspeaker, while removing the negative voltage from pin 7.

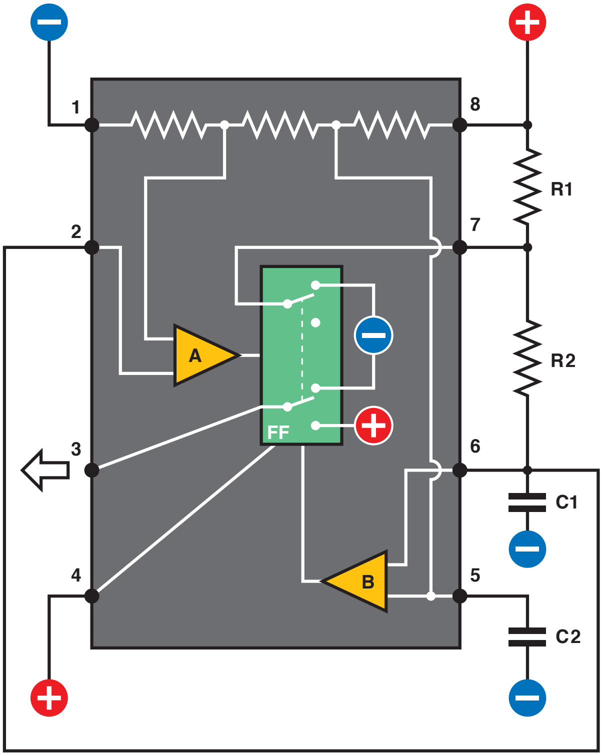

Figure 4-23. *When the 555 timer is used in astable mode, resistor R2 is placed between pin 6 and pin 7, and pin 6 is connected via an external wire to pin 2, so that the timer triggers itself.*

Now C1 starts charging, as it did when the timer was in monostable mode, except that it is being charged through R1 + R2 in series. Because the resistors have low values, and C1 is also small, C1 charges quickly. When it reaches 2/3 full voltage, comparator B takes action as before, discharging the capacitor and ending the output pulse from pin 3.

The capacitor takes longer to discharge than before, because R2 has been inserted between it and pin 7, the discharge pin. While the capacitor is discharging, its voltage diminishes, and is still linked to pin 2. When the voltage drops to 1/3 of full power or less, comparator A kicks in and sends another pulse to the flip-flop, starting the process all over again.

Summing up:

1. In astable mode, as soon as power is connected, the flip-flop pulls down the voltage on pin 2, triggering comparator A, which flips the flip-flop to its "down" position.
2. Pin 3, the output, goes high. The capacitor charges through R1 and R2 in series.
3. When the capacitor reaches 2/3 of supply voltage, the flip-flop goes "up" and the output at pin 3 goes low. The capacitor starts to discharge through R2.
4. When the charge on the capacitor diminishes to 1/3 of full voltage, the pull-down on pin 2 flips the flip-flop again and the cycle repeats.

Unequal on/off cycles

When the timer is running in astable mode, C1 charges through R1 and R2 in series. But when C1 discharges, it dumps its voltage through R2 only. This means that the capacitor charges more slowly than it discharges. While it is charging, the output on pin 3 is high; while it is discharging, the output on pin 3 is low. Consequently the "on" cycle is always longer than the "off" cycle. Figure 4-24 shows this as a simple graph.

If you want the on and off cycles to be equal, or if you want to adjust the on and off cycles independently (for example, because you want to send a very brief pulse to another chip, followed by a longer gap until the next pulse), all you need to do is add a diode, as shown in Figure 4-25.

Now when C1 charges, the electricity flows through R1 as before but takes a shortcut around R2, through diode D1. When C1 discharges, the diode blocks the flow of electricity in that direction, and so the discharge goes back through R2.

THEORY

Inside the 555 timer: astable mode (continued)

R1 now controls the charge time on its own, while R2 controls the discharge time. The formula for calculating the frequency is now:

$$\text{Frequency} = 1440 / ((R1 + R2) \times C1)$$

If you set R1 = R2, you should get almost equal on/off cycles ("almost" because the diode itself imposes a small internal voltage drop of about 0.6V). The exact value depends primarily on the manufacturing process used to make the diode.

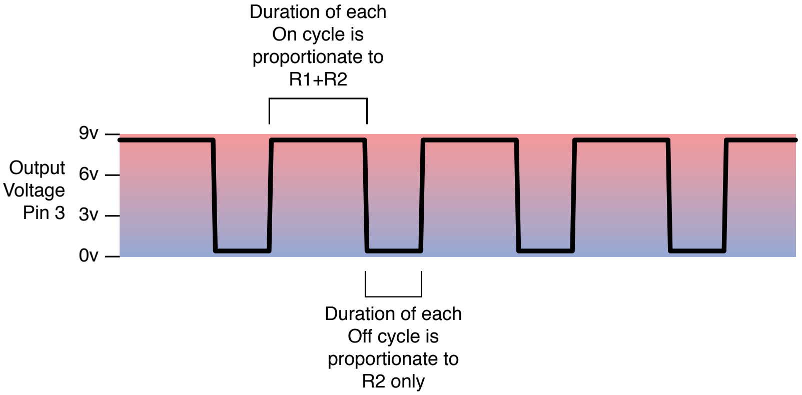

Figure 4-24. *In its usual astable configuration, the timer charges a capacitor through R1+R2 and discharges the capacitor through R2 only. Therefore its output on cycles are longer than its output off cycles.*

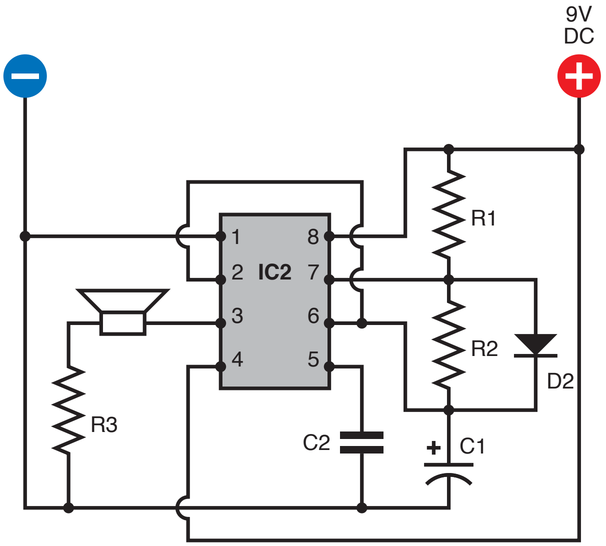

Figure 4-25. *This is a modification of the schematic shown in Figure 4-22. By adding a diode to a 555 timer running in astable mode, we eliminate R2 from the charging cycle of capacitor C1. Now we can adjust the output on cycle with the value of R1, and the output off cycle with the value of R2, so that the on and off durations are independent of each other.*

FUNDAMENTALS

The following table shows 555 timer frequency in astable mode:

- Frequency is in pulses per second, rounded to two figures.
- The horizontal scale shows common resistor values for R2.
- The vertical scale shows common capacitor values for C1. Resistor R1 is assumed to be 1K.
- Resistor R1 is assumed to be 1K.

To calculate a different frequency: double R2, add the product to R1, multiply the sum by C1, and divide the result into 1440. Like this:

$$\text{Frequency} = 1440 / ((R1 + 2R2) \times C1) \text{ cycles per second}$$

In this formula, R1 and R2 are in kilohms, C1 is in microfarads, and the frequency is in hertz (cycles per second). Note that the frequency is measured from the start of one pulse to the start of the next. The duration of each pulse is not the same as the length of time between each pulse. This issue is discussed in the previous section.

47 µF	10	5.7	3.0	1.5	0.7	0.3	0.2	0.1		
22 µF	22	12	6.3	3.1	1.5	0.7	0.3	0.2	0.1	
10 µF	48	27	14	6.9	3.2	1.5	0.7	0.3	0.2	0.1
4.7 µF	100	57	30	15	6.8	3.2	1.5	0.7	0.3	0.2
2.2 µF	220	120	63	31	15	6.9	3.3	1.5	0.7	0.3
1.0 µF	480	270	140	69	32	15	7.2	3.3	1.5	0.7
0.47 µF	1,000	570	300	150	68	32	15	7	3.3	1.5
0.22 µF	2,200	1,200	630	310	150	69	33	15	7	3.3
0.1 µF	4,800	2,700	1,400	690	320	150	72	33	15	7.2
0.047 µF	10,000	5,700	3,000	1,500	680	320	150	70	33	15
0.022 µF	22,000	12,000	6,300	3,100	1,500	690	330	150	70	33
0.01 µF	48,000	27,000	14,000	6,900	3,200	1,500	720	330	150	72
	1K	2K2	4K7	10K	22K	47K	100K	220K	470K	1M

Astable Modifications

In the circuits shown in Figures 4-22 or 4-25, if you substitute a 100K potentiometer for R2, you can adjust the frequency up and down by turning the shaft.

Another option is to “tune” the timer by using pin 5, the control, as shown in the Figure 4-26. Disconnect the capacitor that was attached to that pin and substitute the series of resistors shown. R9 and R11 are both 1K resistors, either side of R10, which is a 100K potentiometer. They ensure that pin 5 always has at least 1K between it and the positive and negative sides of the power supply. Connecting it directly to the power supply won’t damage the timer, but will prevent it from generating audible tones. As you turn the potentiometer to and fro, the frequency will vary over a wide range. If you want to generate a very specific frequency, a trimmer potentiometer can be used instead.

A primary advantage of using pin 5 to adjust frequency is that you can control it remotely. Take the output from pin 3 of another 555 timer running slowly in astable mode, and pipe it through a 2K2 resistor to pin 5. Now you get a two-tone siren effect, as one timer controls the other. If, in addition, you add a 100 µF capacitor between pin 5 and ground, the charging and discharging of the capacitor will make the tone slide up and down instead of switching abruptly. I'll describe this in more detail shortly. This leads me to the whole topic of one chip controlling another chip, which will be our last variation on this experiment.

Chaining Chips

Generally speaking, chips are designed so that they can talk to each other. The 555 couldn't be easier in this respect:

- Pin 3, the output, from one 555 can be connected directly to pin 2, the trigger, of a second 555.
- Alternatively, the output can be sufficient to provide power to pin 8 of a second 555.
- The output is appropriate to control or power other types of chips too.

Figure 4-27 shows these options.

When the output from the first 555 goes high, it is about 70 to 80% of its supply voltage. In other words, when you're using a 9V supply, the high output voltage is at least 6 volts. This is still above the minimum of 5V that the second chip needs to trigger its comparator, so there's no problem.

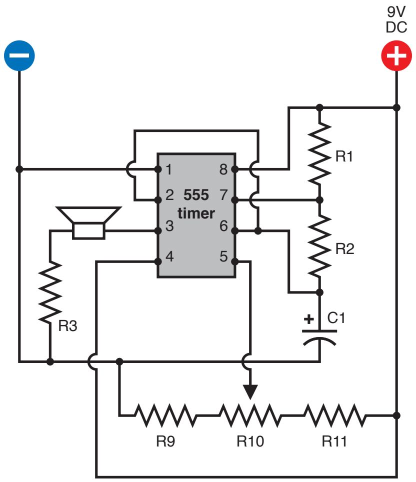

Figure 4-28. *The control (pin 5) is seldom used but can be useful. Varying the voltage on it will adjust the speed of the timer. This circuit enables you to test the behavior of it. Component values:*

R1: 1K
R2: 10K
R3: 100 ohms
R9, R11: 1K
R10: 100K linear potentiometer
C1: 0.047 µF

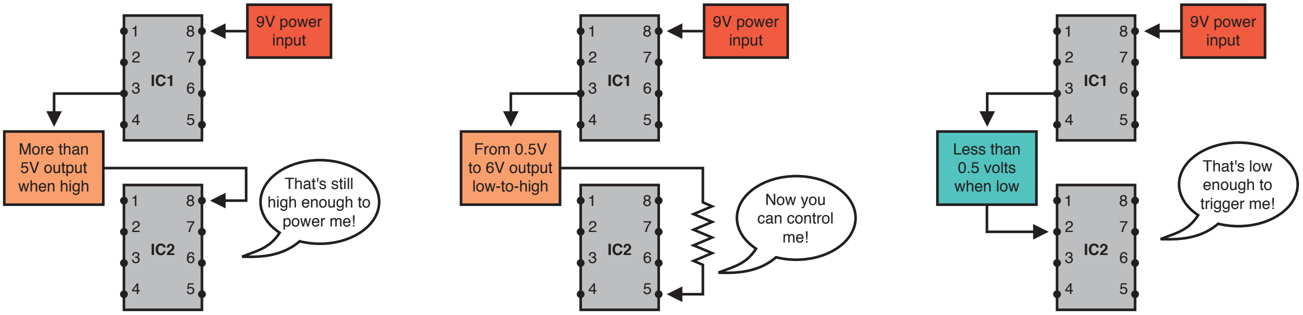

Figure 4-27. *Three ways to chain 555 timers together. The output of IC1 can power a second timer, or adjust its control voltage, or activate its trigger pin.*

You can chain together the two 555 timers that you already have on your breadboard. Figure 4-28 shows how to connect the two circuits that were shown previously in Figures 4-15 and 4-22. Run a wire from pin 3 (the output) of the first chip to pin 8 (the positive power supply) of the second chip, and disconnect the existing wire connecting pin 8 to your power supply. The new wire is shown in red. Now when you press the button to activate the first chip, its output powers the second chip.

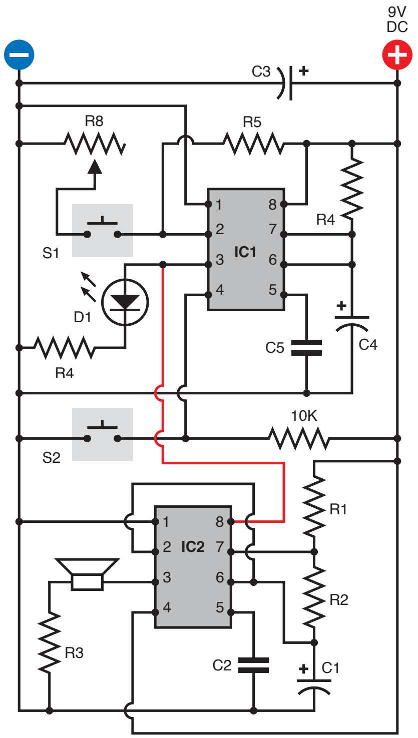

Figure 4-28. *You can combine the two circuits shown in Figures 4-15 and 4-22 simply by disconnecting the wire that provides power to pin 8 of the second timer, and running a substitute wire (shown in red).*

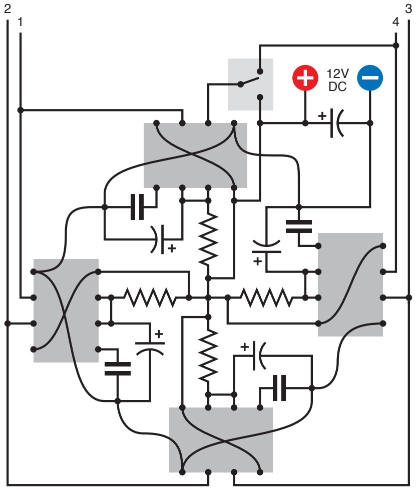

Figure 4-29. *Four 555 timers, chained together in a circle, can flash a series of four sets of LEDs in sequence, like Christmas lights or a movie marquee.*

You can also use the output from one chip to trigger another (i.e., you can connect pin 3 from the first chip to pin 2 of the second). When the output from the first chip is low, it's less than half a volt. This is well below the threshold that the second chip requires to be activated. Why would you want to do this? Well, you might want to have both timers running in monostable mode, so that the end of a high pulse from the first one triggers the start of a high pulse in the second one. In fact, you could chain together as many timers as you like in this way, with the last one feeding back and triggering the first one, and they could flash a series of LEDs in sequence, like Christmas lights. Figure 4-29 shows how four timers could be linked this way, in a configuration that would occupy minimal space (and would be wired point-to-point on perforated board, not on breadboard-format board). Each of the outputs numbered 1 through 4 would have about enough power to run maybe 10 LEDs, if you used relatively high load resistors to limit their current.

Incidentally, you can reduce the chip count (the number of chips) by using two 556 timers instead of four 555 timers. The 556 contains a pair of 555 timers in one package. But because you have to make the same number of external connections (other than the power supply), I haven't bothered to use this variant.

You can even get a 558 timer that contains four 555 circuits, all preset to function in astable mode. I decided not to use this chip, because its output behaves differently from a normal 555 timer. But you can buy a 558 timer and play with it if you wish. It is ideal for doing the "chain of four timers" that I suggested previously. The data sheet even suggests this.

Lastly, going back to the idea of modifying the frequency of a 555 timer in astable mode, you can chain two timers, as shown in Figure 4-30. The red wire shows the connection from the output of the first timer to the control pin of the second. The first timer has now been rewired in astable mode, so that it creates an oscillating on/off output around four times per second. This output flashes the LED (to give you a visual check of what's going on) and feeds through R7 to the control pin of the second timer.

But C2 is a large capacitor, which takes time to charge through R7. While this happens, the voltage detected by pin 5 slowly rises, so that the tone generated by IC2 gradually rises in pitch. Then IC1 reaches the end of its on cycle and switches itself off, at which point C2 discharges and the pitch of the sound generated by IC2 falls again.

You can tweak this circuit to create all kinds of sounds, much more controllably then when you were using PUT transistors to do the same kind of thing. Here are some options to try:

- Double or halve the value of C2.
- Omit C2 completely, and experiment with the value of R7.
- Substitute a 10K potentiometer for R7.
- Change C4 to increase or decrease the cycle time of IC1.

- Halve the value of R5 while doubling the value of C4, so that the cycle time of IC1 stays about the same, but the On time becomes significantly longer than the Off time.
- Change the supply voltage in the circuit from 9 volts to 6 volts or 12 volts.

Remember, you can't damage a 555 timer by making changes of this kind. Just make sure that the negative side of your power supply goes to pin 1 and the positive side to pin 8.

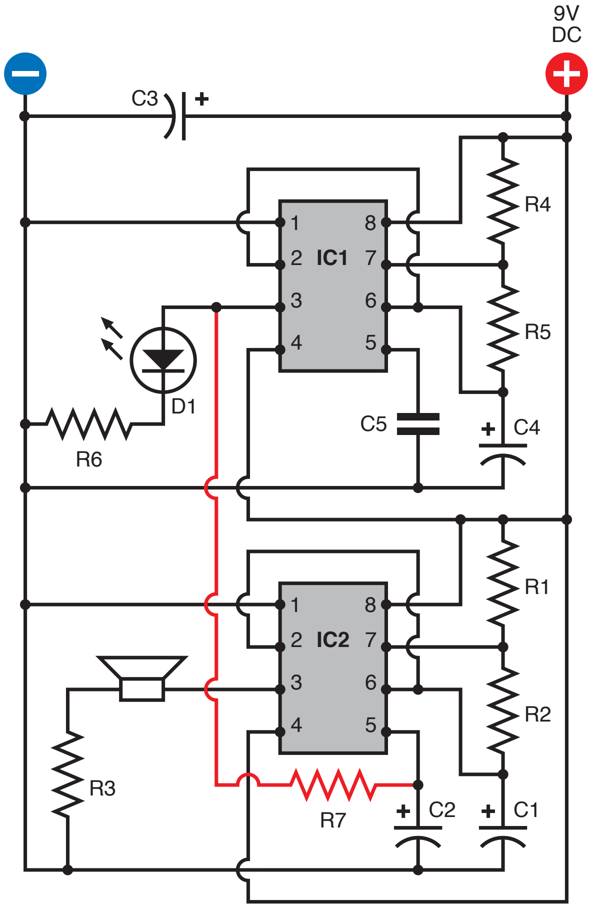

Figure 4-30. *When both timers are astable, but IC1 runs much more slowly than IC2, the output from IC1 can be used to modulate the tone generated by IC2. Note that as this is a substantial modification to the previous schematics, several components have been relabeled. To avoid errors, you may need to remove the old circuit from your breadboard and build this version from scratch. Try these values initially:*

R1, R4, R6, R7: 1K
R2, R5: 10K
R3: 100 ohms
C1: 0.047 µF
C2, C3: 100 µF
C4: 68 µF
C5: 0.1 µF