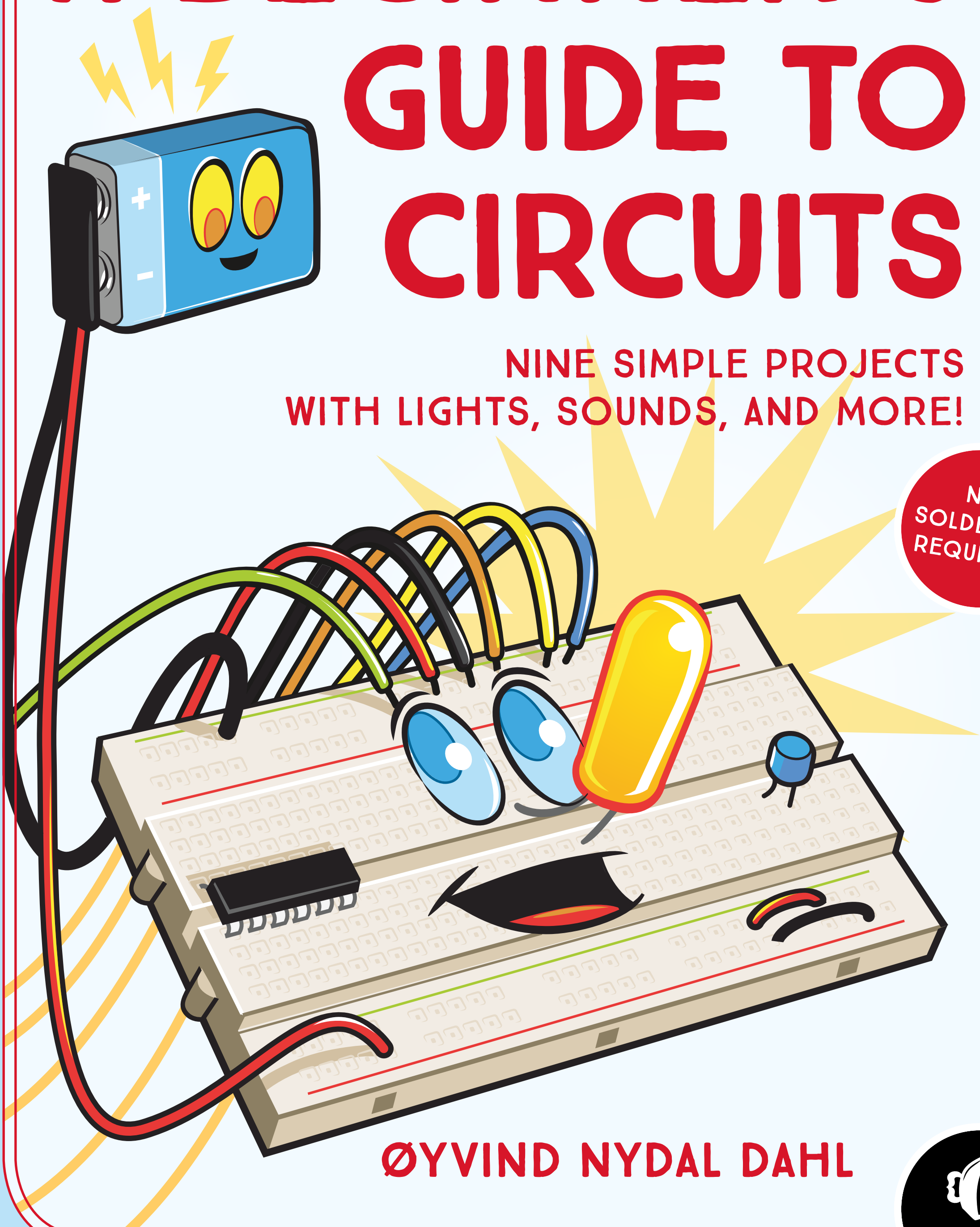
A BEGINNER'S GUIDE TO CIRCUITS



NINE SIMPLE PROJECTS
WITH LIGHTS, SOUNDS, AND MORE!

NO SOLDERING REQUIRED!

ØYVIND NYDAL DAHL

no starch press

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BY ØYVIND NYDAL DAHL

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THIS BOOK IS DEDICATED TO

MY BEAUTIFUL WIFE, PILI.

ABOUT THE AUTHOR

Øyvind Nydal Dahl is a maker, programmer, writer, speaker, blogger, author, tech enthusiast, guitar player, and more. He has a master's degree in electronics from the University of Oslo, helps companies develop new products, and travels the world while teaching electronics workshops. He is the founder of the beginner-friendly blog *https://www.build-electronic-circuits.com/* and the membership site *https://ohmify.com/*.

ABOUT THE TECHNICAL REVIEWER

John Hewes began connecting electrical circuits at an early age, moving on to electronics projects as a teenager. He later earned a physics degree and continued to develop his interest in electronics. John has taught electronics and physics up to an advanced level in the United Kingdom and ran a school electronics club, setting up the website *http://www.electronicsclub.info/* to support the club. He believes that everyone can enjoy building electronics projects, regardless of their age or ability.

BRIEF CONTENTS

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ACKNOWLEDGMENTS

Thanks to the whole team at No Starch Press, especially Riley Hoffman and Zach Lebowski, for helping me create yet another book I'm proud of. Thanks to John Hewes for finding my errors and giving great feedback on how to improve things throughout the book. And a special thanks to Josh Ellingson and Mimi Heft for an awesome book cover!

INTRODUCTION

This book will help you improve your electronics skills. I'll teach you how to interpret circuit diagrams and use breadboards. Then I'll show you, step-by-step, how to build a simple circuit on a breadboard. After that, you're on your own: you'll rely on parts lists and circuit diagrams to build your circuits. Building circuits from diagrams is an essential skill for anyone interested in electronics, from beginners to experts.

THE CIRCUITS

The circuits become more and more difficult to build as you progress through the book. Here's a brief description of each circuit project:

- **Project 1: The Steady-Hand Game** With this super-simple circuit, you'll create an *Operation*-style game where you need a steady hand to win.
- **Project 2: The Touch-Enabled Light** Using a touchpad, you'll build a touch-enabled light switch to turn on a light with your finger.
- **Project 3: The Cookie Jar Alarm** Keep your cookies safe with this cookie jar alarm, which will scare any cookie thieves away with a buzzing noise.
- **Project 4: The Night-Light** Here you'll build a light that turns on in the dark to help you see things at night.
- **Project 5: The Blinking LED** In this project, you'll learn some of the basics of digital electronics and use an integrated circuit to blink an LED.
- **Project 6: The Railroad Crossing Light** Add to your model train set with the railroad crossing light, a classic circuit that everyone should build at some point.
- **Project 7: The Party Lights** This string of blinking lights is a perfect project to prepare for an upcoming party.

- **Project 8: The Digital Piano** Build your own musical instrument from scratch and entertain your friends and family!
- **Project 9: The LED Marquee** In this final circuit, you'll use your new skills to create an awesome LED light show.

You can find resources for the circuits through the book's website at *https://nostarch.com/circuits/*.

THE MATERIALS

All of the materials you'll need to build the circuits in this book are inexpensive and easy to find. Here's a list of all the electronic components you'll need.

#	JAMECO PART NUMBER	VALUE	DESCRIPTION
1	#198731	9 V battery	Standard 9 V battery
1	#109154	Battery clip	Component that connects the battery to the breadboard
1	#20601	Breadboard	Breadboard with around 400 holes
20	#2237044	Jumper wires	Pack of at least 20 breadboard jumper wires
1	Included in #2217511	100 Ω	Standard resistor
4	Included in #2217511	1 kΩ	Standard resistors
2	Included in #2217511	10 kΩ	Standard resistors
1	Included in #2217511	100 kΩ	Standard resistor
2	Included in #2217511	470 Ω	Standard resistors
2	Included in #2217511	47 kΩ	Standard resistors
1	#151116	0.1 µF	Nonpolarized capacitor
1	#31000	4.7 µF	Polarized capacitor
2	#94212	10 µF	Polarized capacitors

NOTE

The part numbers shown here are for Jameco Electronics (https://www.jameco.com/). *These components should be available from any electronics supply store.*

#	JAMECO PART NUMBER	VALUE	DESCRIPTION
1	#158394	100 µF	Polarized capacitor
2	#254801	BC547	Any general-purpose NPN transistor will work
10	#333973	LED	Standard light-emitting diodes; all must have about the same forward voltage (Vf)
1	#904085	NE555	555 timer IC
1	#12749	CD4017B	4017 decade counter IC
1	#44257	74C14	Hex Schmitt trigger inverter
4	#119011	Momentary ON	Tactile mini-pushbuttons
1	#202454	LDR/ photoresistor	Light-dependent resistor (photoresistor) with around 5 to 10 kΩ resistance in light and 200 kΩ or more in dark
1	#2239146	8 Ω speaker	Mini-speaker
1	#2120452	Buzzer	Active buzzer that works with a 9 V battery

With your materials in hand, let's get started!

HOW TO BUILD THE CIRCUITS IN THIS BOOK

For each circuit in this book, I provide a circuit diagram and a parts list. *Circuit diagrams* are drawings that show you how to connect components to build an electronic circuit (see Figure 1).

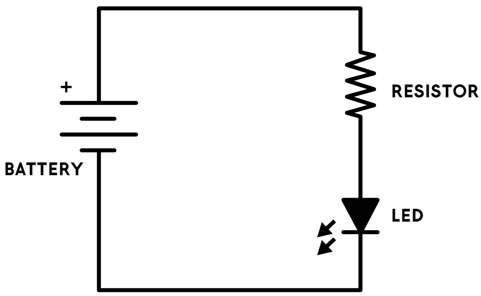


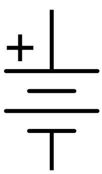
FIGURE 1
This circuit diagram shows you how to connect a battery, a resistor, and an LED.

The parts list tells you which component values you should use—for example, a resistor with a value of 470 Ω or a capacitor with a value of 10 μF. Each component has a symbol, and these symbols are connected with lines that show you how to connect the components. With a little practice with circuit diagrams, you'll quickly learn how to distinguish the different symbols.

What the Components Look Like

In this section, I've listed each component next to the symbol used for it in this book. You might see different symbols for the same component in other electronics books or resources, but in this book, they will be consistent.

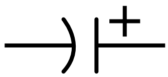
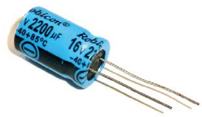
Battery



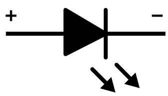
Resistor


Capacitor, nonpolarized

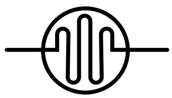

Capacitor, polarized

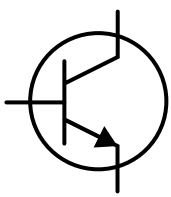
Light-emitting diode (LED)



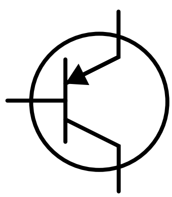
Light-dependent resistor (LDR)




Transistor

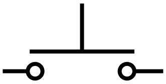


NPN

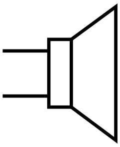


PNP

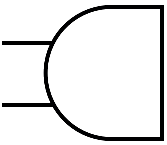
Pushbutton (switch)



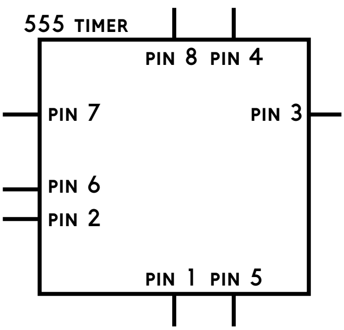
Speaker



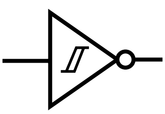
Buzzer



Integrated circuit



Note that some integrated circuits, such as the following Schmitt trigger inverter, use a symbol that represents their function instead of the box symbol.



Building Circuits on a Breadboard

A *breadboard* is a really simple tool for building a circuit. Because you don't have to solder—you just plug in the components—you can easily reuse components if you want to build something else later.

Most breadboards have two areas for components and two areas for power supplies. I've labeled these four areas in Figure 2. The five holes of each row in a component area—labeled with a numeral—are connected by metal strips inside the board. The rows in the left component area are not connected to the rows in the right component area.

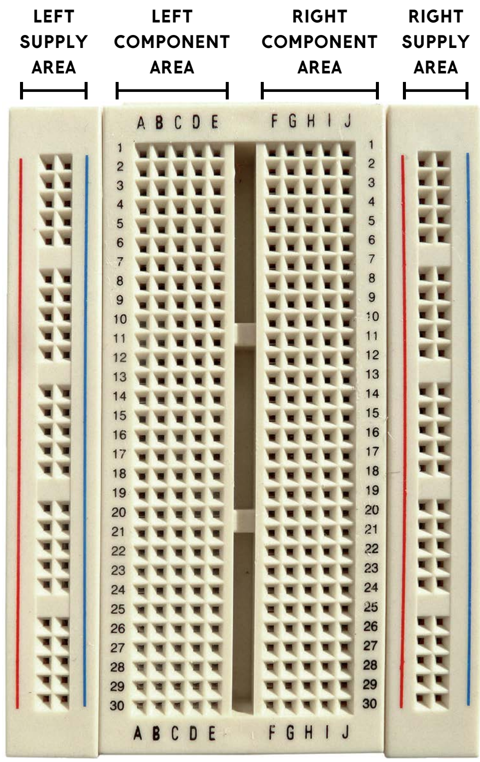


FIGURE 2
A typical breadboard with labeled areas

The wires of a component are called its *pins*, *legs*, or *leads*. To make a connection between two components, you plug their pins into the same row in one of the component areas. If you can't connect them on the same row, you can use a jumper wire in order to make the connection from one row to another.

In Figure 3, the lower pin of the resistor and the upper pin of the LED are connected to each other on row 7. The upper pin of the resistor and the lower pin of the LED don't share a row with any component, so they aren't connected to anything.

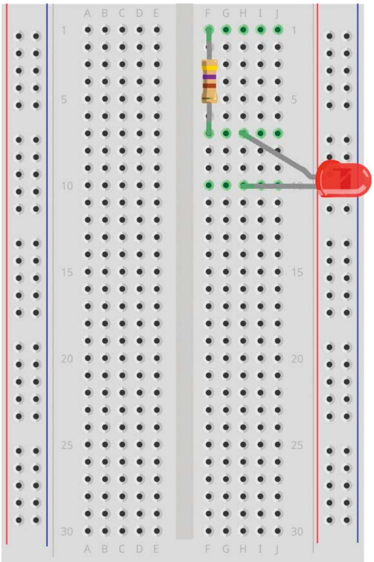


FIGURE 3

Connecting a resistor and an LED

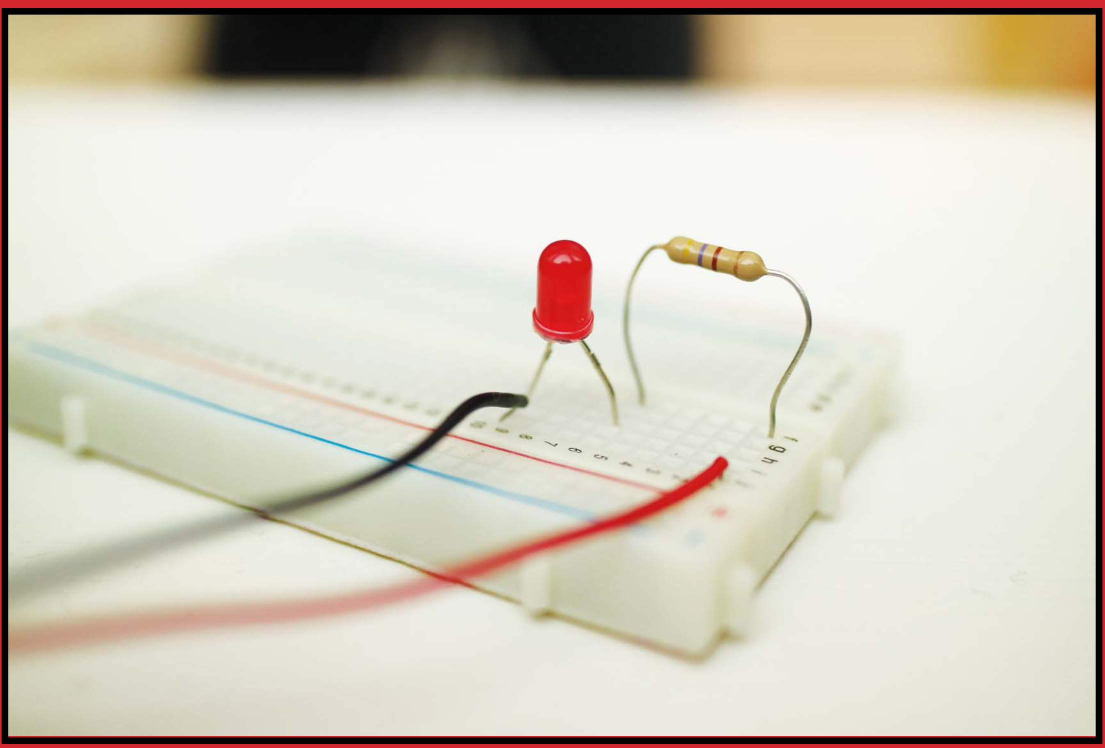
The holes in the supply areas are connected column-wise instead. So if you connect the positive (or plus) terminal of your battery to the top-left hole of the left-hand supply area, all the holes from the top of that column to the bottom will be connected to the positive terminal of your battery.

NOTE

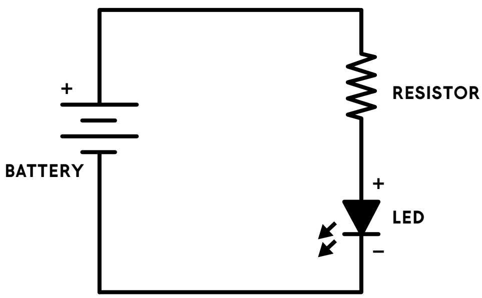
On bigger breadboards, the supply areas are sometimes divided into four areas: top right, top left, bottom right, and bottom left.

BUILD YOUR FIRST BREADBOARD CIRCUIT

THIS SIMPLE CIRCUIT TURNS ON A LIGHT-EMITTING DIODE (LED).



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
Battery	9 V	Standard 9 V battery
Battery clip		Component that connects the battery to the breadboard
Breadboard		Plastic board with around 400 holes
Resistor	470 Ω	Component that reduces the current through the LED
LED	Red	Standard-output light-emitting diode
Jumper wires		Two breadboard jumper wires in different colors

BUILDING THE CIRCUIT

To build this circuit, all you need is a battery, a resistor, and an LED. The resistor reduces the amount of current that flows through the LED. You'll always want a resistor in series with an LED, but it doesn't matter whether you place it before or after the LED. When you add a resistor in series with a circuit, you get less current in the whole circuit. If you don't use a resistor, you risk breaking the LED.

Connecting the Resistor

For this circuit, you'll need a resistor of 470 Ω, or ohms. If you look closely at a resistor, you'll notice it has several colored bands. These colors tell you the value of the resistor. To find a 470 Ω resistor, look for a resistor that has colored bands in this order: yellow, purple, brown, and gold or silver (see Figure 1).

FIGURE 1

A 470 Ω resistor

NOTE
In "Resistor Color Codes" on page 64, you'll find a table that explains the color coding of a resistor.

Connect one pin of the 470 Ω resistor to the top row of column F and attach the other pin to row 7 in the same column, as shown in Figure 2. It doesn't matter which pin you place where; the resistor can be connected either way around.

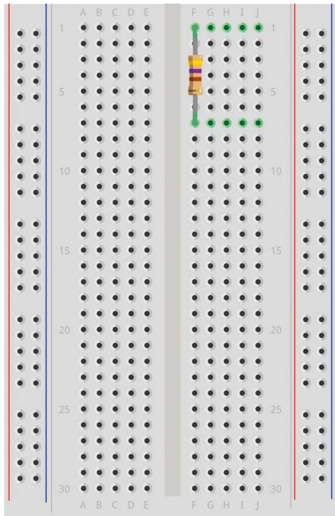


FIGURE 2
Connecting the resistor to the breadboard

Connecting the LED

Now you'll connect your LED to the breadboard. An LED has two sides, called *anode* and *cathode*. For the LED to work, you need to connect the anode to the positive side (+) of the battery and the cathode to the negative side (–). For simplicity's sake, let's call them the positive pin and the negative pin of the LED. I've marked them in Figure 3.

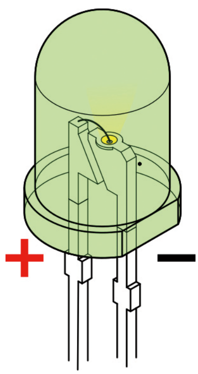


FIGURE 3
An LED with its positive and negative pins

There are two ways to tell which pin is which. Look closely at your LED. If one pin is longer than the other, that's the positive side. If both pins are the same length, look more closely at the round edge at the bottom of the plastic housing. One side of the housing should be flat, as in Figure 3; that's the negative pin. If you're still having a hard time distinguishing between the two pins, place the LED on a flat surface and roll it so you can find the flat side.

Connect your LED's positive pin to column H, row 7, and then connect the negative pin to column H, row 10. Check your connections against Figure 4.

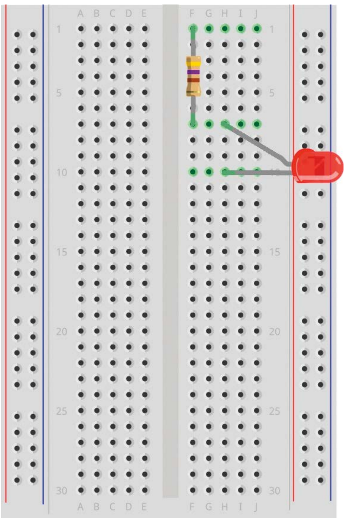


FIGURE 4
Connecting an LED in series with a resistor

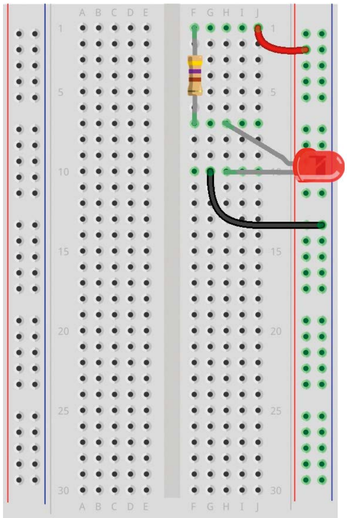
Now the positive pin of the LED is connected to the resistor—as shown in the circuit diagram—but the negative pin, like the upper pin of the resistor, isn't connected to anything.

Connecting to the Power Supply Columns

Next you need to connect wires from the power supply area on the right side of the breadboard to the appropriate rows in the right-hand component area.

If you look at the circuit diagram again, you can see that you need to connect the positive terminal of the battery to the top-most lead of the resistor—the lead in row 1. So use a jumper wire to connect row 1 to the positive column in the supply area. It's common to use the column with a red line next to it as the positive one (to match the red wire of the battery clip). Then connect the LED's negative pin—in row 10—to the negative column in the supply area. Use Figure 5 as a reference.

FIGURE 5
Connecting the component area to the supply area of a breadboard

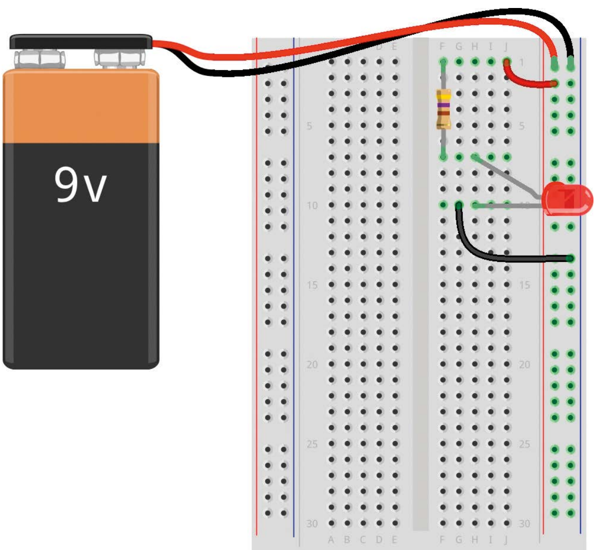


Connecting the Battery

You have your components in place, and you've properly connected the components to the supply area. Now you only need to connect the battery.

First, connect your battery clip to your battery, making sure the exposed metal of the red and black wires does not touch. Next, connect the red wire from your battery clip to the positive column of the right-hand supply area. Finally, connect the black wire from your battery clip to the negative column. Check your circuit against Figure 6.

FIGURE 6
Connecting a battery to a breadboard's supply area



The LED should now be lit up!

WHAT IF THE LED DOES NOT LIGHT UP?

If your LED isn't lighting up, go through each connection on the breadboard to make sure everything is exactly as described in the previous steps.

If you've connected everything correctly and it's still not working, you might have connected the LED the wrong way. Flip it around and try again.

If it's *still* not working, check the resistance value of your resistor using the table in "Resistor Color Codes" on page 64. Your resistor should be 470 Ω.

Still not working? Well, then your LED is likely dead, unfortunately. This can happen easily if you connect it directly to the battery—that is, without putting it in series with a resistor. Replace your LED and try again.

YOU'RE READY TO BUILD THE NINE CIRCUITS!

Now that you've built your first breadboard circuit, you're almost ready to move on to this book's nine circuit projects. First, though, I recommend that you play around a little with the circuit you built in this chapter. Try to really understand why those connections make the circuit work. Understanding this is crucial to building the rest of the circuits in this book. A good test is to see if you can build the circuit again in the *left-hand* component and power supply areas, just by looking at the circuit diagram.

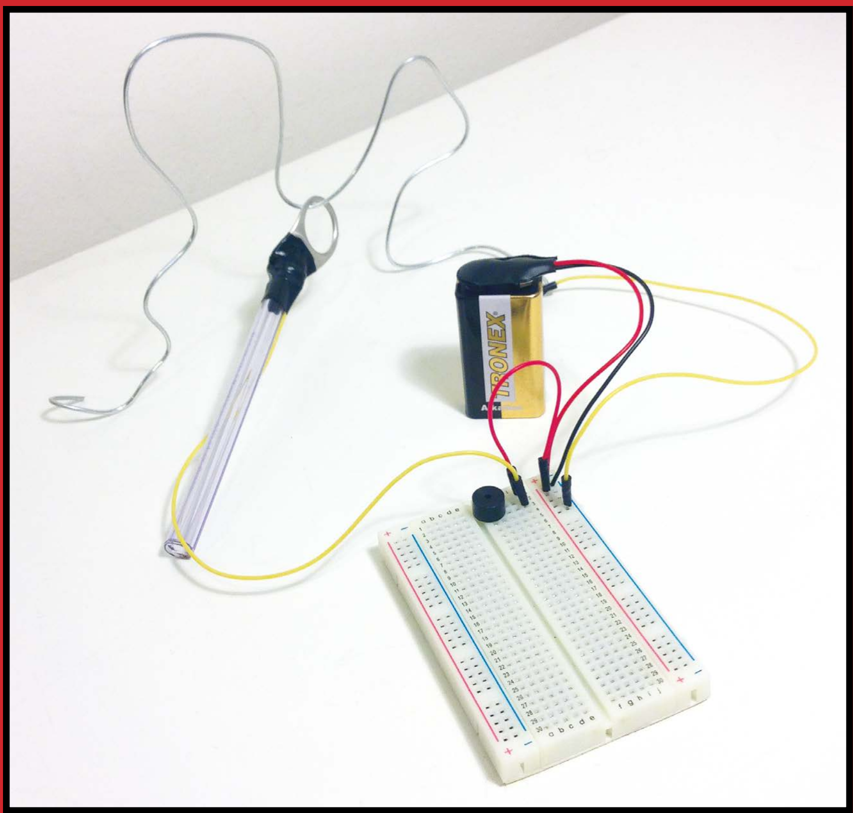
For all the circuits in this book, you'll need a breadboard, a bunch of breadboard jumper wires, a battery, and a battery clip. But for simplicity's sake, you won't see these components in the parts list.

The circuits are sorted by difficulty, starting from the easiest. The challenge is to figure out how to connect each of the circuits on the breadboard. Some of the later circuits might be challenging if you don't have any previous experience with circuits, but the trick is to not give up.

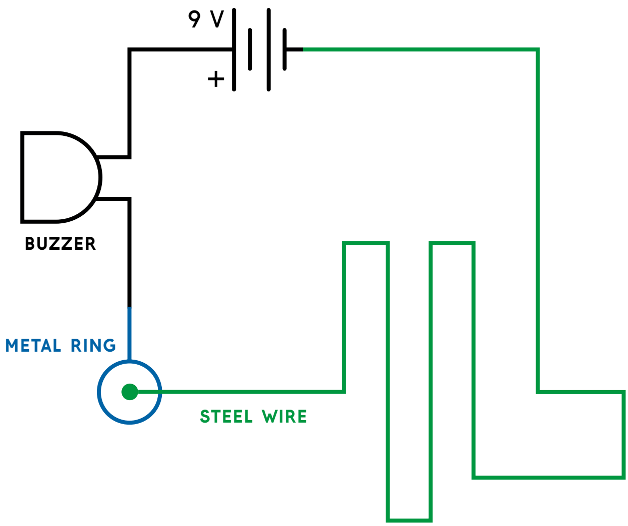
You can find resources for all the circuits through the book's website at *https://nostarch.com/circuits/.*

1
THE STEADY-HAND GAME

THIS CIRCUIT WILL SOUND A BUZZER IF YOU LET THE RING TOUCH THE WIRE.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	DESCRIPTION
Buzzer	Buzzer that works with 9 V battery
Steel wire	Bare and stiff wire, like a clothes hanger
Metal ring	Bare metal ring, like a soda can ring
An old pen	Old pen for mounting the metal ring
Tape	Electrical tape is best, but any tape should work

ABOUT THE CIRCUIT

You might have grown up playing a game called *Operation*, in which you play a surgeon who uses tweezers to remove silly ailments (like brain freeze and charlie horse) from a patient. If you aren't careful and touch the wrong place, a terrifying buzzer sounds and the patient's nose lights up.

In this chapter, you'll build a steady-hand game that works a lot like *Operation*, but the goal is to move a ring along a track of steel wire without letting them touch. If you get the ring all the way to the other side without touching the wire, you win. If the ring touches the wire, the buzzer sounds and you lose.

The circuit works on the basic principle that for anything to happen in electronics, there must be a *closed loop*—a continuous path from the positive to the negative side of the battery where the current can flow. When the metal ring doesn't touch the steel wire, you don't have a closed loop, so nothing happens. When the ring touches the steel wire, you get a closed loop and the buzzer sounds.

Connecting the Battery to the Buzzer

The circuit itself is pretty simple. You just need to connect the buzzer and the battery, in the black part of the circuit diagram, to the breadboard. Make sure you place the plus sign (+) on the buzzer toward the positive terminal of the battery. Remember, the red lead of the battery clip connects to the positive terminal on the battery.

Add two loose jumper wires—one from the negative (–) side of the buzzer and one from the negative battery terminal (the two yellow wires in Figure 1-1).

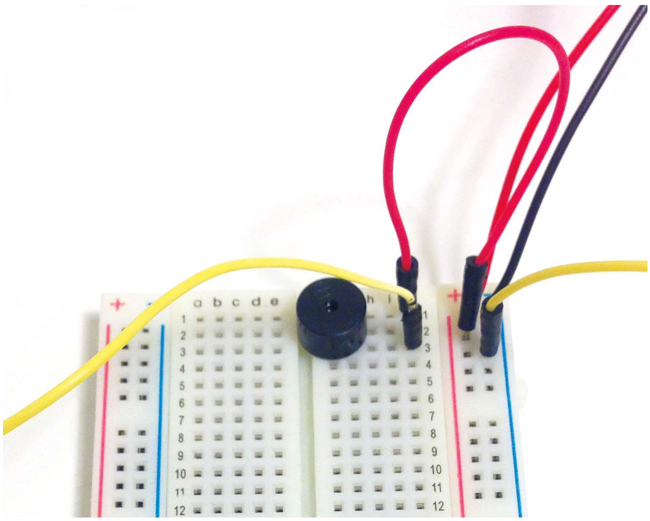


FIGURE 1-1
Connecting the battery to the buzzer

Now you just need to create a game track and integrate it into the circuit.

Creating the Game Track

To create the game track, use a steel wire from a clothes hanger and bend it into the shape you want. Connect the steel wire to the breadboard using the loose jumper wire from the negative connection of the battery and some tape, as in Figure 1-2. Make sure the metal at the end of the jumper wire is touching the steel wire so there's a good electrical connection between them.

FIGURE 1-2
Taping a jumper wire to the game track

Any kind of tape should work, but I recommend electrical tape as it sticks well to metal.

Connecting the Metal Ring to the Breadboard

For the metal ring, you can use the tab from a can, like the one shown in Figure 1-3.

FIGURE 1-3
Use the metal ring from a can to loop around the track.

Tape the ring and the loose end of the jumper wire from the negative side of the buzzer to the end of an old pen, making sure the jumper wire has a good connection with the metal (see Figure 1-4). The pen offers players something to easily grasp as they navigate the turns in the track.

FIGURE 1-4
Taping the metal ring to a pen

That's it! The circuit is complete, so now you can test how steady your hands are!

COMMON MISTAKES

If the circuit is not working properly, double-check that you haven't made any of these common mistakes:

- Not creating a good connection between the jumper wire and the track
- Not creating a good connection between the jumper wire and the ring
- Connecting the buzzer wrong way (remember that it has a positive and a negative side)

If you are still struggling with this circuit, find more resources through the book's website at *https://nostarch.com/circuits/.*

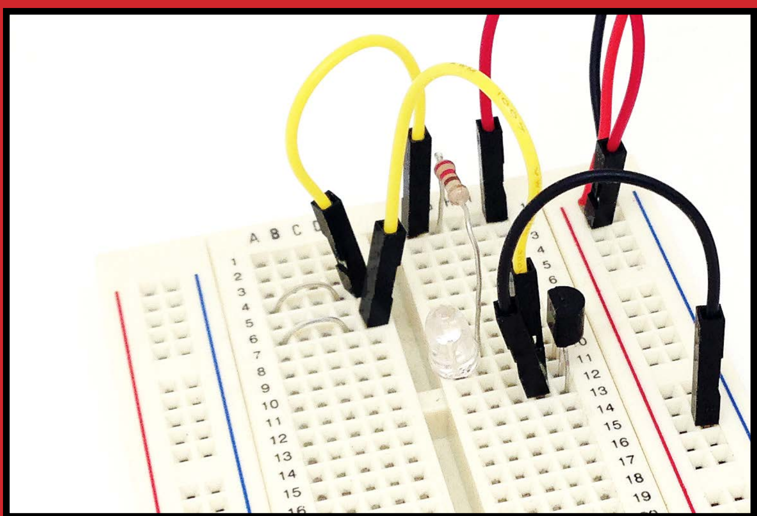
A QUIET ALTERNATIVE

If you prefer a noiseless game—so you can play without disturbing other people—you can modify the game so it uses an LED instead of a buzzer. Just replace the buzzer in the circuit with an LED. Don't forget to put the LED in series with a resistor (just like your first breadboard circuit); otherwise, you risk breaking the LED.

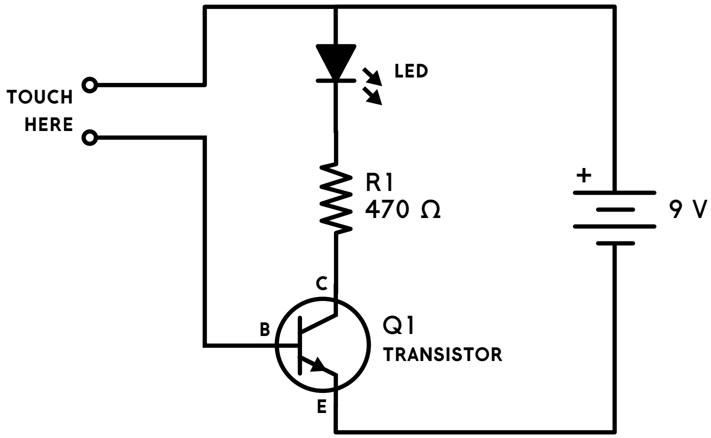
2

THE TOUCH-ENABLED LIGHT

LIGHT UP AN LED WHEN YOU TOUCH A TOUCHPAD MADE FROM TWO UNINSULATED WIRES.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1	470 Ω	Standard resistor
LED	Red/yellow/green	Standard-output light-emitting diode
Q1	BC547	General-purpose NPN transistor

INTRODUCING THE TRANSISTOR

In this circuit, you'll use a transistor—specifically, an *NPN transistor*. It has three pins:

- Top pin: Collector
- Middle pin: Base
- Bottom pin: Emitter

Don't worry about the meaning of the pin names—just think of them as labels.

Turn the transistor so its label is facing you and compare the pins to Figure 2-1. Note, however, that different manufacturers arrange the pins differently. The safest bet when you're using a new transistor is to check the pinout in the transistor's documentation, or *datasheet*.

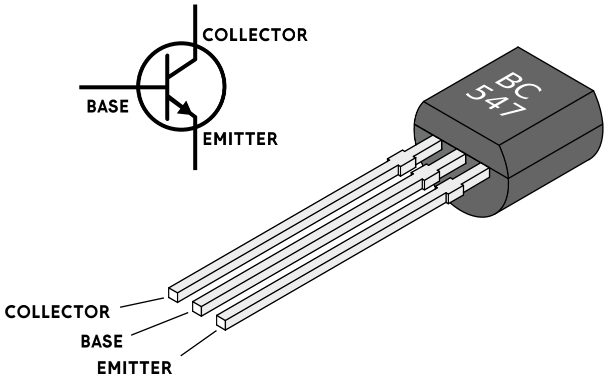


FIGURE 2-1
An NPN transistor and its pinout

ABOUT THE CIRCUIT

In this project, you'll build a touch sensor by creating a touchpad from two uninsulated wires. Using a transistor, you can detect when someone touches the touchpad and turn a light on. When someone touches the touchpad, the high resistance in their finger connects the base of the transistor to the positive terminal of the battery. This completes the path from the battery's positive terminal to its negative terminal and allows a tiny current to flow from the base to the emitter.

The current is tiny because human skin is a poor conductor and has a high resistance; the current is too weak to light an LED directly, which is why we need the transistor. The tiny current flowing from the base to the emitter will turn the transistor "on" so that a larger current can flow from the collector to the emitter. Current will flow through the LED and the resistor—making the LED light up—only if the transistor is turned on.

When nobody is touching the touchpad, the base is left unconnected, so no current will flow through that pin and the LED will not light up.

To create the touchpad, clip off a bit of your LED's pins, as shown in Figure 2-2. Then place these horizontally on two rows. Leave one hole open for connecting the touchpad to the rest of the circuit.

CAUTION

Do not allow the two metal pads of the touchpad to make contact when the battery is connected. If they touch, a lot of current will flow from the base to the emitter and you might damage your transistor, making it unusable.

FIGURE 2-2
Cutting the pins off your LED to use as a touchpad

Place the cut-off pins horizontally on two rows. Make sure you leave one hole in each of those rows open so you can connect the touchpad to the rest of the circuit.

COMMON MISTAKES

If you can't get the circuit to work, make sure you haven't made any of these common mistakes:

- Mixing up the pins of the transistor
- Destroying the transistor by letting the two metal pads of the touchpad make direct contact
- Connecting the LED backward
- Dry fingertip; try wetting your finger a bit (damp skin has a lower resistance, allowing a bit more current to flow)

If you're still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

To get current to flow in a circuit, you need a path from the battery's positive terminal to its negative terminal. If you don't have this path, current can't flow and the LED won't light up. Turning the transistor "on" allows current to flow through it from its collector to its emitter.

To turn the transistor on, you need to have current flowing from its base to its emitter, which in turn lets current flow from its collector to its emitter. The amount of current flowing from the base to the emitter controls how much current can flow from the collector to the emitter.

You can find the relationship between the base-to-emitter and the collector-to-emitter currents from the *current gain* of the transistor. The gain is often called h_{FE} or β (beta). For a general-purpose transistor like the one you're using here, the current gain is about 100. This means the collector-to-emitter current can be up to 100 times larger than the base-to-emitter current.

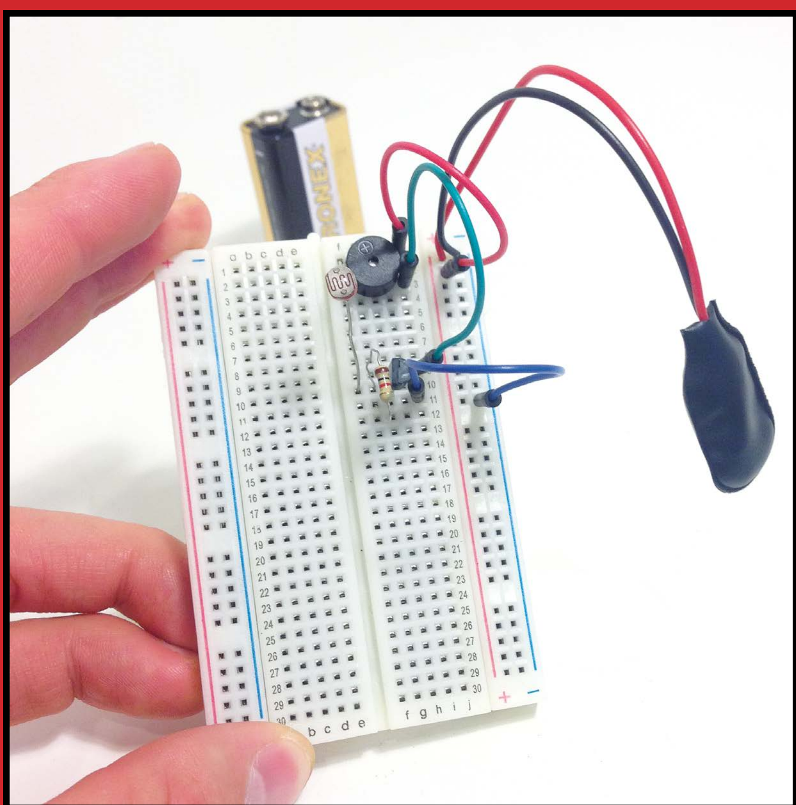
In this circuit, when no one is touching the touchpad, there is no current flowing from the base to the emitter. This means the transistor is “off” and there’s no current flowing through the resistor and the LED.

When you touch the touchpad, your finger acts as a resistor from the positive terminal of the battery to the base of the transistor. A tiny current runs through the base to the emitter, which produces a larger current from the collector to the emitter. Current will also run through your LED, lighting it up.

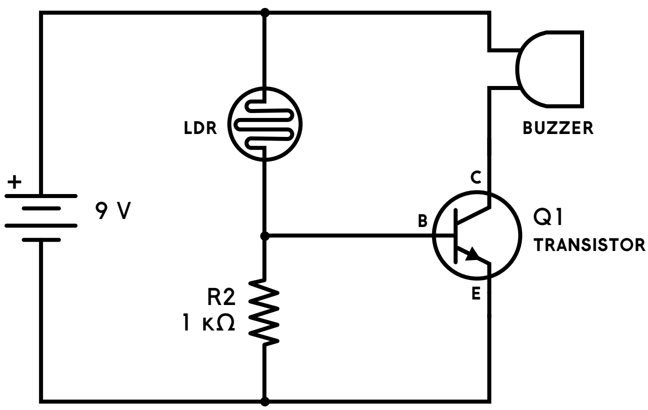
3

THE COOKIE JAR ALARM

THIS ALARM BUZZES WHEN IT SENSES LIGHT.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
LDR	200 kΩ	Light-dependent resistor (photoresistor) with around 5 to 10 kΩ resistance in light and 200 kΩ or more in dark
Q1	BC547	Any general-purpose NPN transistor
R2	1 kΩ	Standard resistor
Buzzer		Active buzzer that works with a 9 V battery

ABOUT THE CIRCUIT

Do you want to keep people from stealing cookies from your cookie jar? Or keep spies from snooping in your treasure chest? Then this circuit is for you.

This circuit stays quiet when it's in a dark place, such as in a cookie jar with the lid on. But once the lid comes off and lets light inside, the circuit sounds an alarm that should scare off any cookie thieves.

The circuit uses a *light-dependent resistor (LDR)* to detect light. Its resistance changes when it detects more or less light. The more light the LDR detects, the lower the resistance.

The LDR and R2 make up a *voltage divider*, which controls the amount of input voltage at the base of the transistor, switching the transistor off or on depending on how much light is detected.

Once your circuit is complete, you can put it in your cookie jar or treasure chest to protect your precious belongings.

COMMON MISTAKES

If you can't get the circuit to work, check for the following:

- The resistance value of R2 is too high or too low. Refer to "Resistor Color Codes" on page 64 for help reading the resistor's color coding.
- You connected the transistor the wrong way. If you need a refresher on connecting an NPN transistor, refer to Project 2.

If you want to make the circuit more or less sensitive to light, replace R2 with a higher (more sensitive) or lower (less sensitive) resistance value.

If you have questions about this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

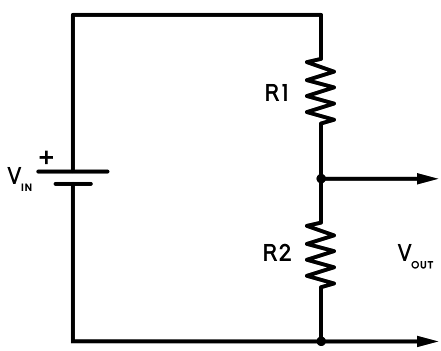
HOW THE CIRCUIT WORKS

The buzzer will sound only if current is flowing through it, which can happen only if there is a path from the battery's positive terminal to its negative terminal. This means the alarm will sound only if the transistor is turned "on" so that current can flow from the battery's positive terminal through the buzzer, then from the transistor's collector to its emitter, and finally back into the battery's negative terminal.

As you saw in Project 2, for a transistor to be turned "on," current needs to flow from its base to its emitter. This happens only when the voltage between the base and emitter is about 0.7 V. When the voltage is much less than 0.7 V, no current flows through the base, and emitter and the transistor is off.

In the circuit diagram in Figure 3-1, you can see that the voltage from the base to the emitter is equivalent to the voltage across R2.

FIGURE 3-1
Creating a voltage divider



The LDR and R2 are connected to form a voltage divider. The LDR is R1 in this diagram. The formula for calculating the output voltage from a voltage divider is:

$$V_{out} = V_{in} \times \frac{R2}{R1 + R2}$$

If it's dark, the LDR has around 200 kΩ resistance or more, and R2 is always 1 kΩ. You're using a 9 V battery, so V_{in} is 9 V. If you plug these values into the formula, you get:

$$V_{out} = 9 \times \frac{1,000}{200,000 + 1,000}$$

This gives you a V_{out} of about 0.04 V, which is too low for the transistor to turn on.

If it's light, the LDR has around 10 kΩ resistance or less. Plug this into the voltage divider formula, and you'll get:

$$V_{out} = 9 \times \frac{1,000}{10,000 + 1,000}$$

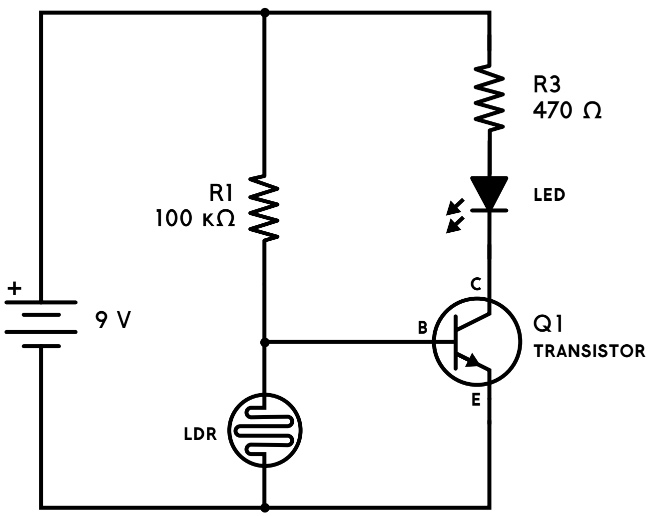
In this case, V_{out} equals about 0.8 V. This is more than the 0.7 V required for current to flow from the base to the emitter, so the transistor turns "on," allowing current to flow through the buzzer, collector, and emitter and sounding the alarm.

4

THE NIGHT-LIGHT

THIS CIRCUIT IS A NIGHT-LIGHT THAT TURNS ON IN THE DARK.

THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
LDR	~10 k to ~200 kΩ	Light-dependent resistor (photoresistor) with around 5 to 10 kΩ resistance in light and 200 kΩ or more in dark
Q1	BC547	Any general-purpose NPN transistor
R1	100 kΩ	Standard resistor
R3	470 Ω	Standard resistor
LED		Standard-output light-emitting diode

ABOUT THE CIRCUIT

This circuit turns on an LED when it gets dark. During the day, the light stays off, but at night, it can help you see things like the keyhole in your front door or a glass of water on your nightstand.

This circuit is similar to the one in Project 3, but here the transistor controls an LED instead of a buzzer. Remember, the LED has a resistor connected in series to limit its current.

Also, the resistor and LDR, which form the voltage divider that sets the voltage to the base of the transistor, have switched places.

In Project 3, the LDR was the upper resistor on the voltage divider. So when the resistance of the LDR was *low*—that is, when it sensed light from the opened cookie jar—the transistor turned on. In this circuit, the LDR is the lower resistor of the voltage divider. That means the transistor turns on when the resistance of the LDR is *high*, which happens when it's dark.

COMMON MISTAKES

If your circuit isn't working correctly, check for the following:

- The R1 resistance value is too high, so the LED never turns on. If you change R1, its resistance must not be less than 1 kΩ (see "How the Circuit Works" next).
- The R1 resistance value is too low, so the LED is always on.
- You used the wrong value for R3—either too much or too little resistance.
- You connected the transistor the wrong way.
- You connected the LED the wrong way.

You can change the circuit's sensitivity to light by changing the resistance of R1, but as mentioned previously, it must not be less than 1 kΩ (otherwise you may destroy the transistor).

If you're still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

Just as in the Cookie Jar Alarm, the LDR and the resistor (R1) make up a voltage divider in this circuit. But since the LDR is now placed at the bottom of the voltage divider (between the transistor base and negative battery terminal), it works opposite to how the Cookie Jar Alarm works. In this circuit, when it's dark and the LDR resistance is high, the voltage on the transistor's base will be high enough to turn the LED on (shown in Figure 4-1). This means the transistor switches on the LED when it's dark.

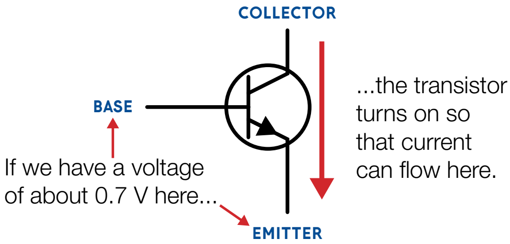


FIGURE 4-1
The amount of current flowing from the base to the emitter determines how much current can flow from the collector to the emitter.

The LDR that I used for this project has around 5 to 10 kΩ resistance when it's in light. With the 100 kΩ resistor (R1), the LED will turn on when the value of the LDR goes above about 10 kΩ.

A curious thing about this circuit is that the R1 resistor will also set the maximum brightness of the LED. This is because R1 determines the amount of current that flows into the base of the transistor, which in turn decides how much current can flow into the collector.

For a general-purpose transistor like the one you're using in this project, the amount of current flowing from the collector to the emitter can be up to 100 times greater than the current flowing from the base to the emitter.

That means that if you have 0.1 mA of current flowing from the base to the emitter, you can have up to 10 mA flowing from the collector to the emitter. If 10 mA is the upper limit from the collector to the emitter, that's the maximum that can flow through the LED too.

The current that flows into the base of the transistor has to first flow through R1. Not all the current that flows through R1 will go into the base—some will go through the LDR too—but when it's dark, the LDR resistance is so high that you can simplify for the sake of the calculation and say that all the current goes into the base.

Finding the current (I) through R1 is actually quite simple. Just find the voltage (V) across the resistor and divide it by the resistor value (R):

$$I = \frac{V}{R}$$

This calculation is based on *Ohm's law*, which describes the relationship among voltage, resistance, and current. You can learn more about Ohm's law at *https://www.build-electronic-circuits.com/ohms-law/.*

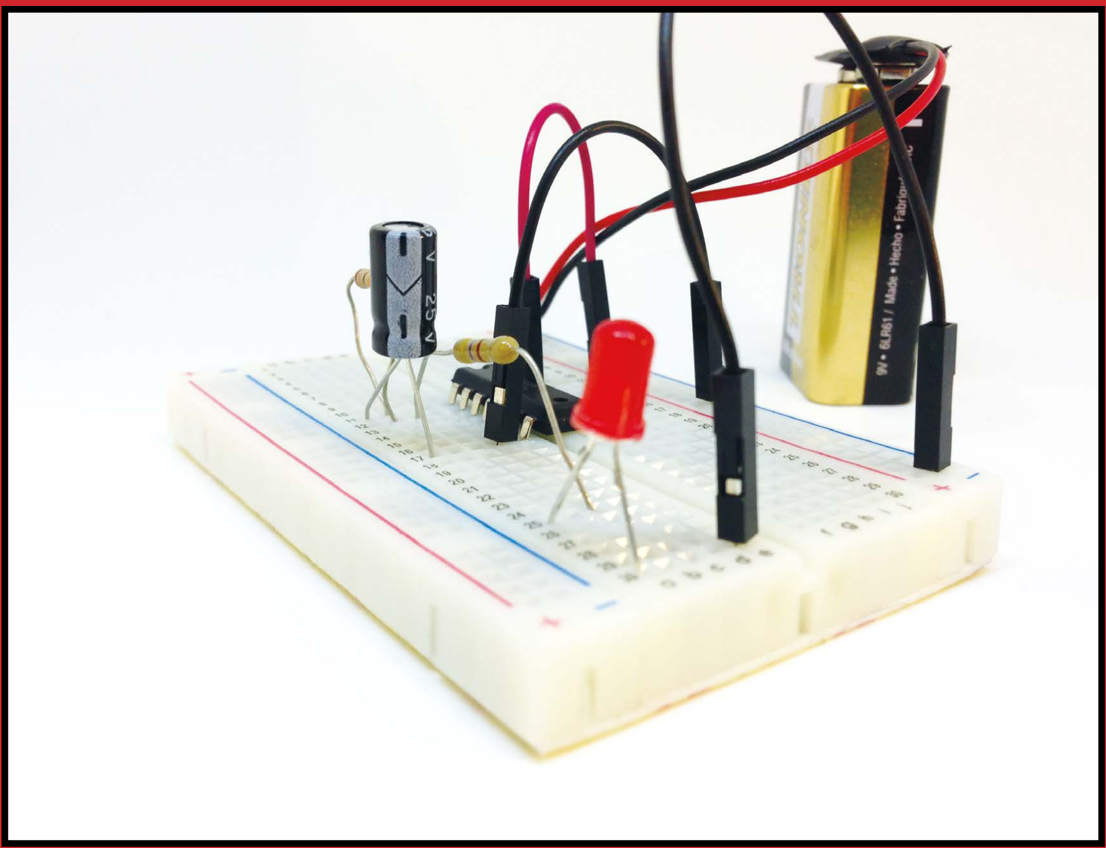
The voltage on the upper side of the resistor is easy. It's 9 V because it is connected to the positive terminal of the battery, but what about the lower side? Since you're looking for the maximum current that can flow through the transistor, it only makes sense to look at the current when the transistor is turned on. When the transistor is on, the voltage on the base of the transistor is around 0.7 V.

So you have 9 V on one side and 0.7 V on the other. This means you have 8.3 V across the resistor (R1). Using Ohm's law, you can divide 8.3 V by 100,000 Ω (= 100 kΩ) to get 0.000083 A (= 0.083 mA), so the maximum current that can flow through the LED and into the collector of the transistor is 100 times larger, or 8.3 mA.

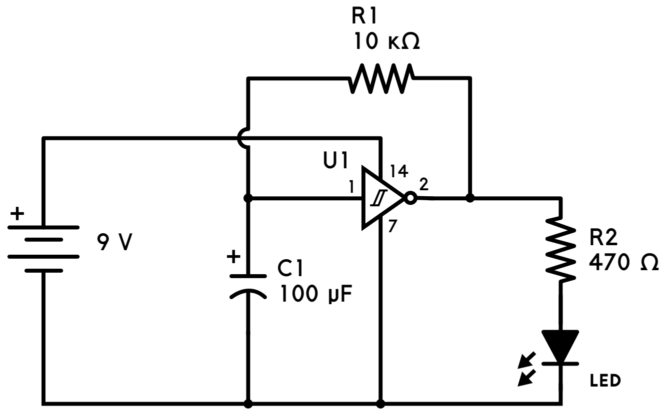
Since R1 is limiting the current to a value that is safe for the LED, in this circuit you could actually skip the R3 resistor, whose job is also to limit the current to the LED.

5
THE BLINKING LED

THIS CIRCUIT MAKES AN LED BLINK ON AND OFF.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
U1	74C14	Hex Schmitt trigger inverter
C1	100 µF	Polarized capacitor
R1	10 kΩ	Standard resistor
R2	470 Ω	Standard resistor
LED		Standard-output light-emitting diode

ABOUT THE CIRCUIT

One of the first things I wanted to learn in electronics as a kid was how to blink a light. You can do this in one of several ways, but this circuit is probably the easiest way to do it, especially because it requires so few components. In fact, you need only five components, including the resistor and the LED.

The circuit works around an *inverter*, a component that outputs the opposite voltage of what it takes in. If it gets a *high* voltage in, it gives a *low* voltage out, and vice versa. A high voltage is a voltage close to the positive supply voltage (9 V in this case), and a low voltage is a voltage close to 0 V.

The output of the inverter (U1) is connected back to the input with a resistor, which causes *oscillation*, or jumping back and forth between high and low voltage. If the inverter input is high, then its output will be low. You connect that low-voltage output back to the inverter's input, and because the input is low, the output will be high. That high-voltage output is directed back to the inverter's input, and so on.

To slow down the oscillation enough to see the LED blink, you use a capacitor on the input of the inverter. A *capacitor* stores and discharges energy; the charging and discharging of the capacitor in this circuit (C1) will increase the time it takes for the input to go from low to high and from high to low. The resistor (R1) controls how much current goes back and forth to charge and discharge the capacitor, so the size of R1 and C1 determines the speed of the oscillation.

You should use a 74C14 IC *Schmitt trigger* inverter; its threshold for switching from high to low voltage is different from the threshold for switching from low to high. This ensures that the inverter doesn't get stuck in a state in between high and low.

The Schmitt trigger inverter comes as a 14-pin *integrated circuit (IC)*, a single chip with its own internal circuitry. The number next to each pin in the circuit diagram represents the pin number on the integrated circuit. Figure 5-1 shows how the pins are arranged on the 74C14 IC Schmitt trigger inverter.

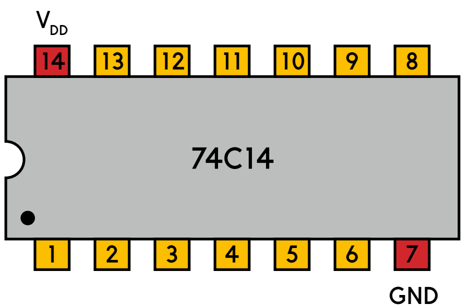
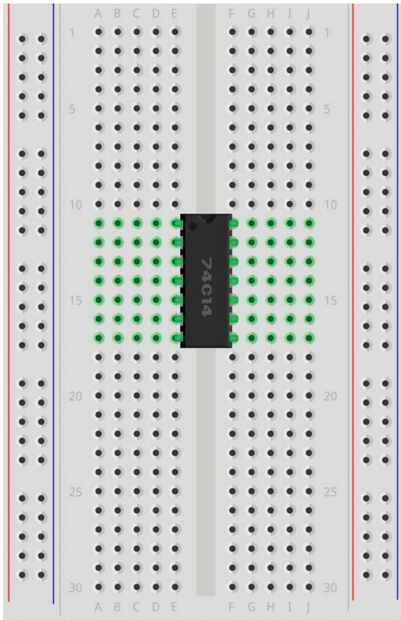


FIGURE 5-1
Pinout of the 74C14 Schmitt trigger inverter

To connect an IC to a breadboard, you need to connect it across the two component areas, as in Figure 5-2.

FIGURE 5-2
Connecting the inverter IC across the two component areas



This will give you connections for pins 1 to 7 on the left component area and connections for pins 8 to 14 on the right component area. Note that pin 1 is indicated by a circular indentation in one corner of the inverter or a notch at its pin 1 end.

COMMON MISTAKES

If your circuit isn't working correctly, you might have made one of these common mistakes:

- Forgetting to connect V_{DD} (pin 14) to the positive terminal of the battery
- Forgetting to connect GND (pin 7) to the negative terminal of the battery
- Misreading the pinout of the IC
- Mistaking the positive LED pin for the negative pin

To decrease the blinking speed, increase either the capacitor value or the resistance value of R1 (or both). To increase the blinking speed, decrease those values.

If you are still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

An inverter is a device that inverts its input. So a low input becomes a high output, and vice versa. You can build a simple inverter using a transistor and a couple of resistors, as shown in Figure 5-3.

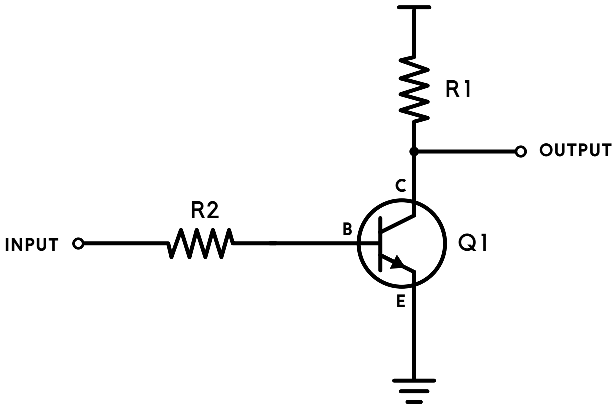
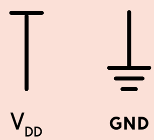


FIGURE 5-3
An inverter built using a transistor

When you have a *low* voltage (0 Volts) on the input, the transistor is turned off, and when you have a high voltage (9 Volts) on the input, the transistor is turned on.

SIMPLIFYING WITH THE V_{DD} AND GND SYMBOLS

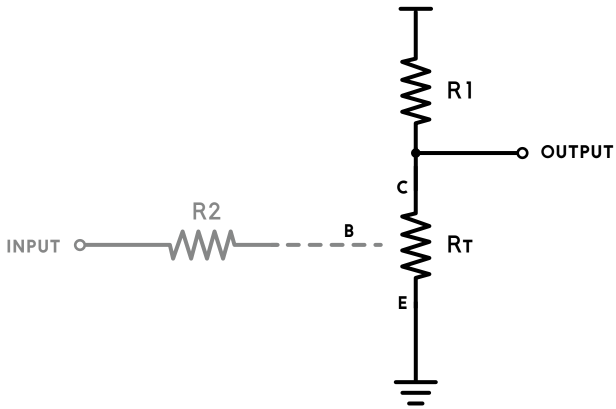
The symbols at the top and bottom of Figure 5-3 are common in circuit diagrams. For the battery-driven circuits in this book, V_{DD} is where you connect the positive terminal of your battery, and GND is where you connect its negative terminal.



You can use these two symbols to simplify your circuit diagrams a bit, because they let you omit the battery symbol and the lines connecting it to the circuit.

When the transistor is off, you can think of it as a resistor with very high resistance between the collector and emitter (Rt in the diagram), and when the transistor is on, you can look at it as a resistor with zero resistance. You might find this easier to understand if you ignore the input for a second and just look at the output circuit, as in Figure 5-4. You may have noticed that you get a voltage divider.

FIGURE 5-4
The simple resistor with the transistor turned off



In Project 3, you learned how to calculate the voltage from a voltage divider. For R1 and Rt in Figure 5-4, the formula for calculating the output voltage becomes:

$$V_{out} = V_{in} \times \frac{Rt}{R1 + Rt}$$

When you have a high input, you can look at the transistor as a resistor (Rt) with zero resistance (or a wire). If you replace Rt with 0 in this formula, it doesn't matter what the other values are: you'll get 0 V as the output voltage, so that's a low output.

When you have a low input, you can look at the transistor as a resistor with really high resistance—say, billions of ohms. A normal value for R1 is 1,000 Ω, so if you have 9 V as V_{in} and you try to put 1 billion ohms into the formula as Rt, the result is 9 V—a high output.

The Schmitt trigger inverter works in a similar way, but with some additional components built into the IC to make the circuit switch from high to low and from low to high at different input voltages.

The 74C14 chip you use in this project is an integrated circuit containing six inverters, which is why it has so many pins. You can see the circuit's pinout and internal inverters in Figure 5-5.

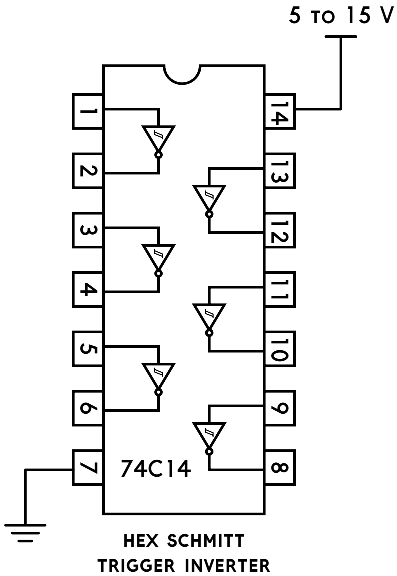


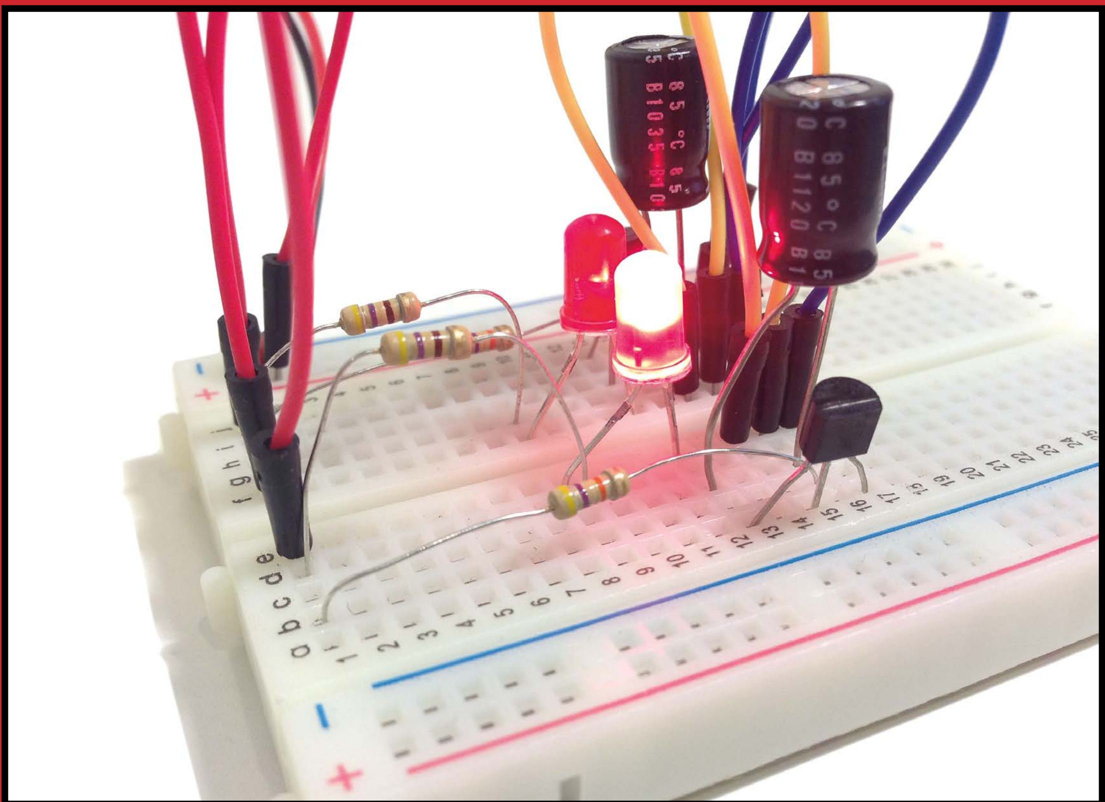
FIGURE 5-5
The 74C14 chip contains six inverters

Because of its small size, using an integrated circuit like the 74C14 saves you a lot of space compared to building the inverter from scratch.

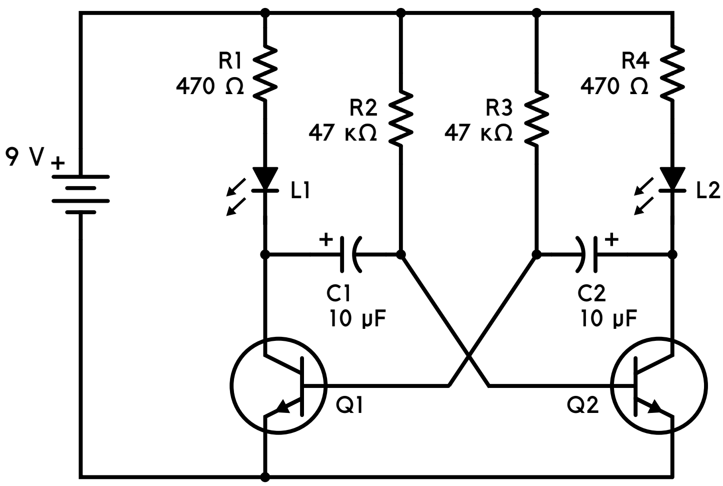
6

THE RAILROAD CROSSING LIGHT

THIS CIRCUIT FLASHES TWO LEDS IN AN ALTERNATING PATTERN.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1, R4	470 Ω	Standard resistor
R2, R3	47 kΩ	Standard resistor
Q1, Q2	BC547	Any general-purpose NPN transistor
C1, C2	10 μF	Polarized capacitor
L1, L2		Standard-output light-emitting diode

ABOUT THE CIRCUIT

This circuit makes two LEDs flash in an alternating pattern. You can use it for a model railroad crossing, for example, or for eyes on a toy robot.

This is a classic circuit called an *astable multivibrator*. In Project 5, you made an LED blink using an inverter that turned itself on and off continuously. The astable multivibrator is a circuit that instead uses two transistors that turn each other on and off. To really grasp what's going on in this circuit, you need to have a strong understanding of the basics of electronics, especially around how voltages behave in circuits with capacitors.

COMMON MISTAKES

This circuit has a lot of connections, so it's very easy to overlook something. I often make mistakes when I build this one, even though

I've done it plenty of times. If your circuit isn't working correctly, check for the following:

- Using 470 Ω resistors where you need 47 kΩ and vice versa
- Connecting the LEDs the wrong way
- Mixing up the transistor pins
- Having pins accidentally touch, especially around the transistors
- Connecting the capacitors the wrong way around

If you want to change the flashing speed, try replacing the two capacitors (C1 and C2) and the resistors (R2 and R3) with other values.

If you're still struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THE CIRCUIT WORKS

Having a good handle on the basics of electronics, especially on how voltages behave in circuits with capacitors, will help you understand what's happening here. In this circuit, shown in Figure 6-1, the LED on the left-hand side is lit when the transistor on the left-hand side (Q1) is on, and the LED on the right-hand side is lit when the transistor on the right-hand side (Q2) is on. Transistor Q1 is controlled by the voltage at the junction between R3 and C2, while transistor Q2 is controlled by the voltage at the junction between R2 and C1.

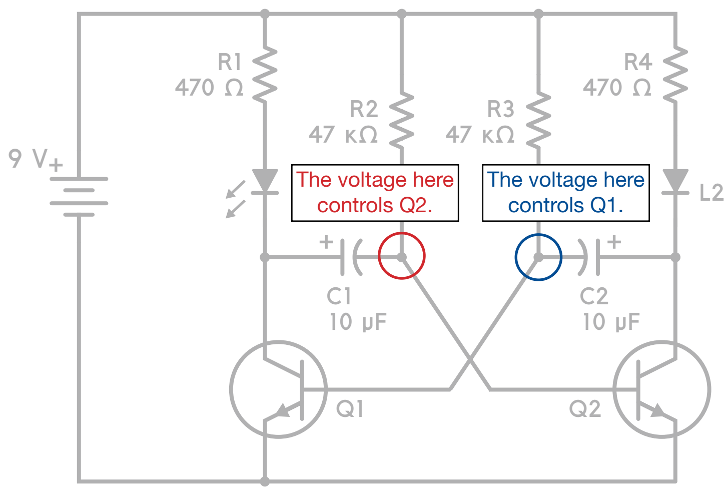


FIGURE 6-1
The voltage on the left node controls the right transistor (Q2) and vice versa.

Next, you have to look in detail at the voltages across the two capacitors. If you aren't comfortable with how voltages and currents behave in a circuit, I recommend reading this article before you move on: *https://www.build-electronic-circuits.com/kirchhoffs-law/*.

Here are two things to keep in mind before diving into the explanation:

- Voltage is always measured between two points. When we talk about the voltage at a specific point, we mean the voltage measured from that point to the battery's negative terminal—that's why the negative terminal is 0 V.
- Throughout this book, we're using the transistor as a switch. It needs 0.7 V on the middle pin (base) to turn on. When the transistor is on, its top pin (collector) is connected to its bottom pin (emitter) so that current can flow through it. This also means that the top pin has the same voltage as the bottom pin when the transistor is on. When the transistor is off, there's no connection between the top pin and the bottom pin, so no current can flow.

Let's start by looking at the circuit when LED L1 is lit and the other LED is off. L1 is lit only when transistor Q1 is turned on. Remember that Q1 is turned on only if it has 0.7 V on its base. Since the negative (–) side of capacitor C2 is connected to the base of Q1, this must also be 0.7 V.

The positive side of C2 is connected to the 9 V through R4 and L2, and it almost instantly charges to about 8 V (some voltage is used up across LED L2). You may be thinking, "Hey, if there is current flowing through R4 and L2, why isn't L2 lit?" The reason is that as soon as the voltage on the right side of the capacitor rises to 8 V, no more current flows through the LED, and thus it doesn't light up.

Figure 6-2 shows the voltages we have found so far.

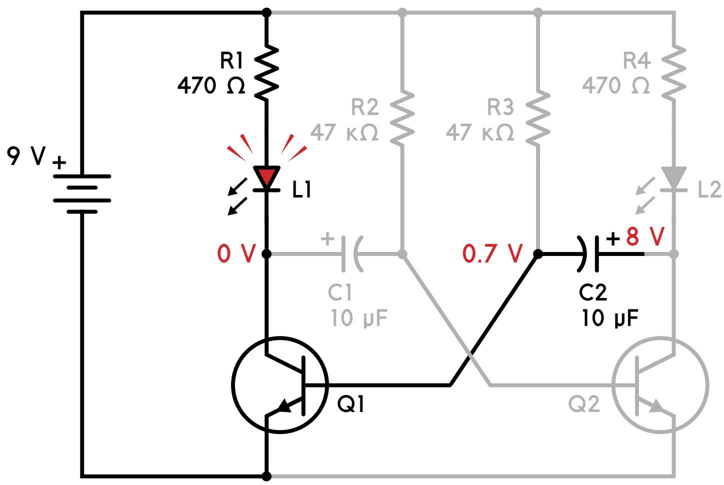


FIGURE 6-2
The voltage on the positive side of capacitor C2 quickly reaches about 8 V when the LED on the left is lit.

Now let's look at the voltages for the other transistor, Q2.

Since the transistor is off, its base must be lower than 0.7 V. The negative side of C1 is connected to the base, so that means it is also lower than 0.7 V. But the negative side of C1 is also connected to 9 V through resistor R2, which means it is being charged and the voltage is slowly increasing from below 0.7 V, as shown in Figure 6-3.

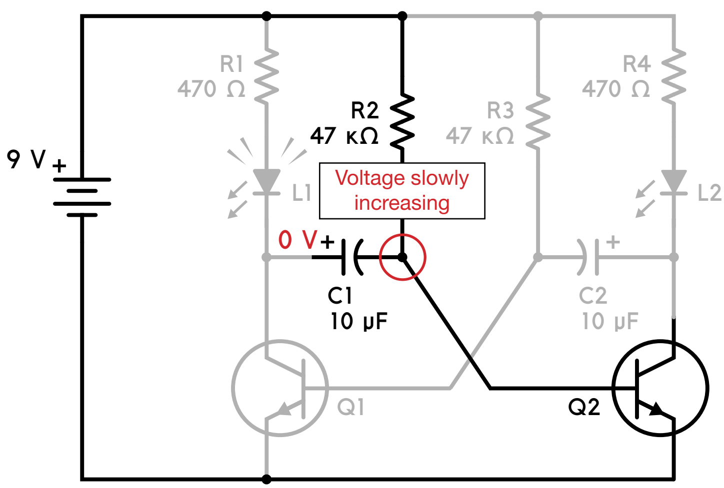


FIGURE 6-3
The voltage on the right of C1 is somewhere below 0.7 V, but increasing, when the left LED is lit.

So the voltage on the negative side of C1 is rising, and when it reaches 0.7 V, the action starts. When the negative side of C1 reaches 0.7 V, transistor Q2 gets 0.7 V on its base and turns on; this means the LED on the right also turns on.

When Q2 turns on, something interesting happens with the voltages on capacitor C2: from Figure 6-2, we know that C2 had 0.7 V on its negative side and 8 V on its positive side. Or, put another way, the negative side was 7.3 V lower than the positive side. But now that Q2 turns on, the voltage on the positive side of C2 is suddenly pulled down to 0 V through the transistor. The internal charge of the capacitor doesn't change instantly, though, so the voltage difference across C2 initially stays the same, with the negative side 7.3 V lower than the positive side. But now that the positive side is 0 V, the negative side becomes 7.3 V below 0, or –7.3 V! With –7.3 V on the negative side of C2, the base of transistor Q1 also gets –7.3 V, which turns it off (see Figure 6-4).

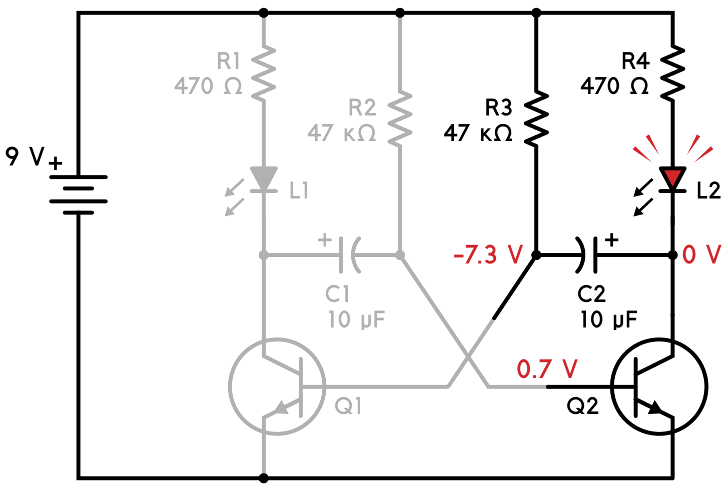


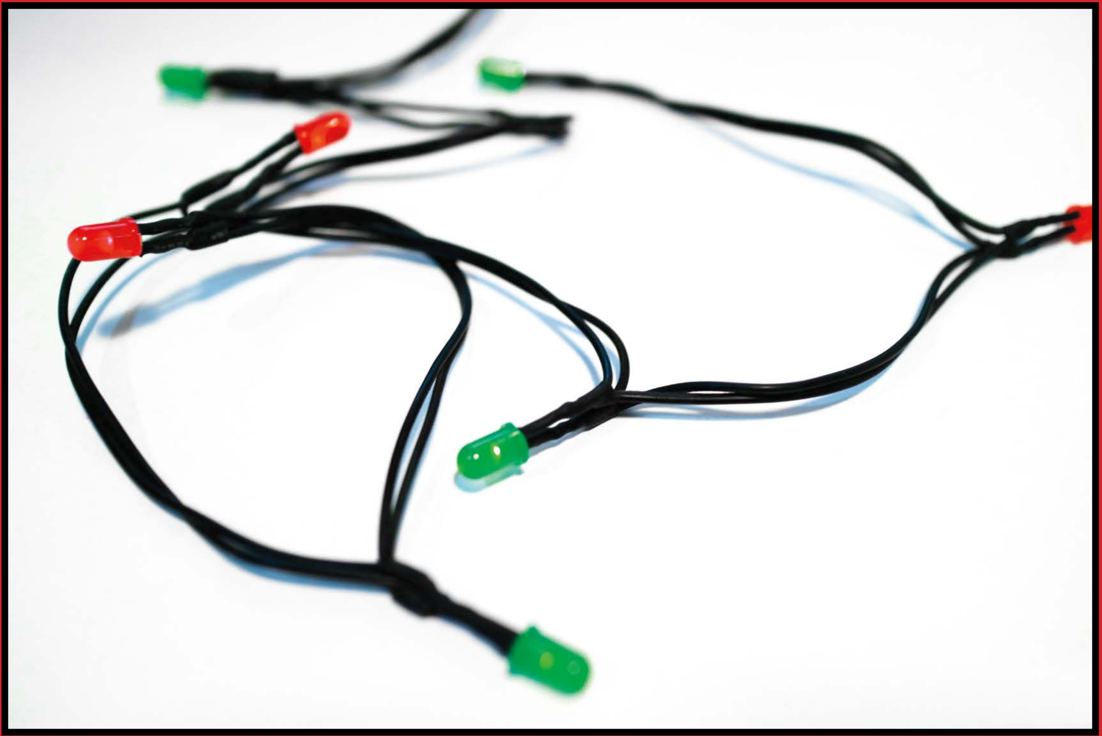
FIGURE 6-4

When transistor Q2 turns on, the transistor and LED on the left turn off.

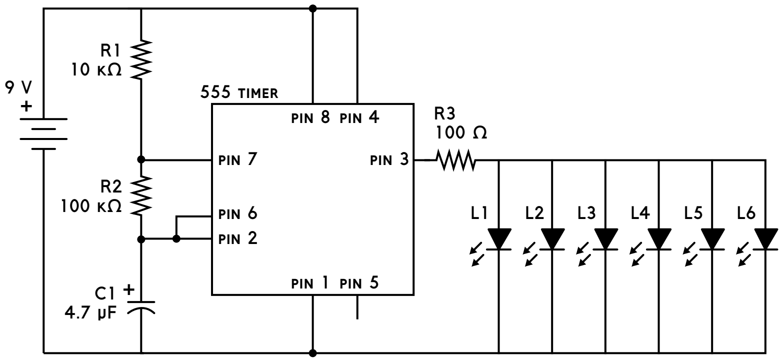
So now, the left LED and transistor have turned off. And the right LED and transistor have turned on, as shown in Figure 6-4. The negative side of C2 starts at –7.3 V and is being charged through resistor R3—and is therefore rising. Since this is connected to the base of transistor Q1, when it reaches 0.7 V, Q1 turns on again, and the cycle repeats. The two transistors keep alternating between on and off, which makes the two LEDs alternate between on and off as well.

7
THE PARTY LIGHTS

THIS CIRCUIT CONNECTS MULTIPLE BLINKING LEDS TO MAKE STRING LIGHTS.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1	10 kΩ	Standard resistor
R2	100 kΩ	Standard resistor
R3	100 Ω	Standard resistor
C1	4.7 μF	Polarized capacitor
L1 to L6	Red, yellow, or green	Standard LEDs; all must have about the same forward voltage (Vf)
U1	NE555	555 timer IC

ABOUT THE CIRCUIT

If you want to make something cool for a party, this is the circuit for you. It's a simple way to make several LEDs blink at the same time. By roping all the lights together on a single long wire, you can hang them in a window or use them to decorate a tree.

The circuit uses a *555 timer*, which is a classic integrated circuit that makes things turn on and off repeatedly; you can see the timer's pinout in Figure 7-1.

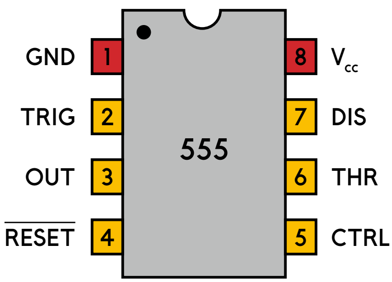


FIGURE 7-1
555 timer pinout

Two resistors (R1 and R2) and a polarized capacitor (C1) set the blinking speed, while a third resistor (R3) determines the current that goes out to the LEDs.

COMMON MISTAKES

If your circuit isn't working correctly, you might have made one of these common mistakes:

- Connecting one or more of the LEDs the wrong way
- Connecting the 555 timer the wrong way
- Connecting the capacitor the wrong way around
- Mixing up the pin numbers of the IC and connecting components to the wrong pin

You can add or remove LEDs by changing the value of the resistor (R3). If each LED needs 10 mA and you want to use five LEDs, you need 5 × 10 mA, or 50 mA, through the resistor. You can use *Ohm's law* to figure out the correct resistor value:

$$\frac{V}{I} = R$$

Ohm's law states that the resistance is equal to the voltage across the resistor divided by the current flowing through it. In your five-LED example, that translates to the following equation:

$$\frac{V_{BAT} - V_{LED}}{I} = \frac{7\ V}{50\ mA} = 140\ \Omega$$

In this case, you are working with a 9 V battery and there's about 2 V across the LEDs, so you get 7 V as the numerator. You divide that by the 50 mA calculated earlier to get 140 Ω of resistance. Note that your circuit will require less resistance as you add more LEDs and more resistance as you remove LEDs.

NOTE

A 555 timer can give out only 100 to 200 mA in total. Check your chip's datasheet for the exact value.

If you're struggling with this circuit, you can ask questions and make comments through the book's website at *https://nostarch.com/circuits/.*

HOW THE CIRCUIT WORKS

Figure 7-2 shows the inside of the 555 timer. The green box marked "flip-flop" is a simple memory device with two states: output high (flip) and output low (flop). It has two inputs, set (S) and reset (R), which either set the output (Q) to high or reset it to low. Q is always the opposite of $\overline{Q}$.

The two triangles you see are *comparators*. If the comparator input marked with + has a higher voltage than the one marked with –, the output is high; otherwise, the output is low.

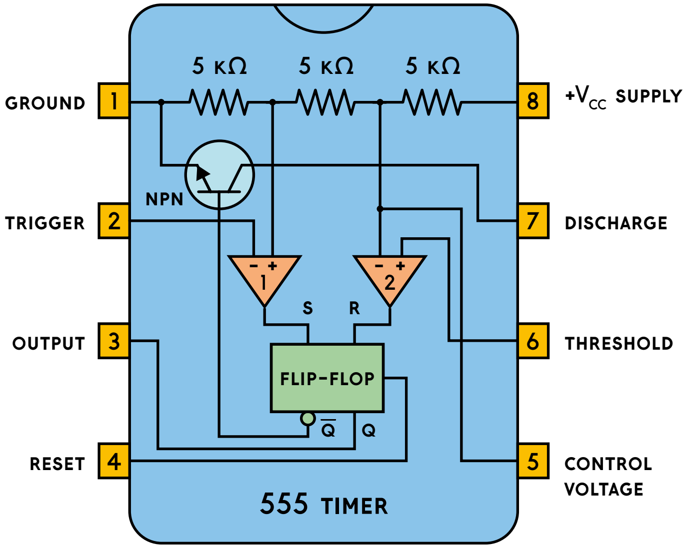


FIGURE 7-2
The inside of a 555 timer

The three 5 kΩ resistors between V_{CC} and Gnd are the reason for the name "555." They divide the V_{CC} voltage by three and set fixed voltages for each of the comparators: one-third of the V_{CC} voltage goes to the positive (+) input of comparator 1, and two-thirds of the V_{CC} voltage goes to the negative (–) input of comparator 2.

If you look at the output (pin 3) in Figure 7-2, you'll see that it's connected to the output of the flip-flop. This means that if the flip-flop is "set," the output is high; otherwise, it is low. If you look at the input to the flip-flop, you'll see that the two comparators handle setting and resetting the flip-flop. This means that the pins responsible for making the output turn on and off are pins 2 and 6.

Pin 2 is labeled *Trigger* and is responsible for setting the output high. When the voltage on pin 2 goes lower than one-third of V_{CC}, comparator 1 outputs high and sets the flip-flop, which in turn sets the output high. Pin 6 is labeled *Threshold*; when its voltage exceeds two-thirds of the V_{CC}, it is responsible for resetting the output to low.

Refer back to the circuit diagram at the beginning of this project. For this project's circuit, pins 2 and 6 are connected to each other, so when the voltage on these pins goes high, the output goes low. When the voltage on these pins goes low, the output goes high. That means you need to switch the voltage on these pins between high and low in order to switch the output between low and high.

Pin 7 is very important for making this happen. It is labeled *Discharge*. Inside the chip, pin 7 is connected to a transistor, as shown in the figure. The transistor is controlled by $\overline{Q}$, the opposite value of the output. This means that when the output is low, the transistor gets a high value and turns on, connecting pin 7 to ground. Otherwise, the transistor is off and leaves pin 7 unconnected.

The moment we apply power to our circuit, capacitor C1 is completely discharged. That means pin 2 (Trigger) is low, which means pin 3 (the output) is high. This also means that pin 7 (Discharge) is not connected to anything internally.

Since C1 is connected to 9 V through R1 and R2, C1 will start to charge, and the voltage on its positive pin will begin to rise. This means the voltage on pin 6 (Threshold) is increasing, too. When the voltage becomes high enough on Threshold, the output changes from high to low, and pin 7 (Discharge) is connected internally to ground.

In this situation, when pin 7 is connected to ground, the capacitor will start to discharge (hence the pin name Discharge) through R2, down to ground at pin 7. So the voltage across the capacitor decreases and continues to do so until the voltage on pin 2 is so low that it "triggers." When it triggers, the output switches from low to high, and pin 7 is disconnected from ground again.

Now we're in the same situation as when we started, where the capacitor is charging so that the voltage over the capacitor increases. This process repeats indefinitely.

The following is a brief overview of each pin on the 555 timer:

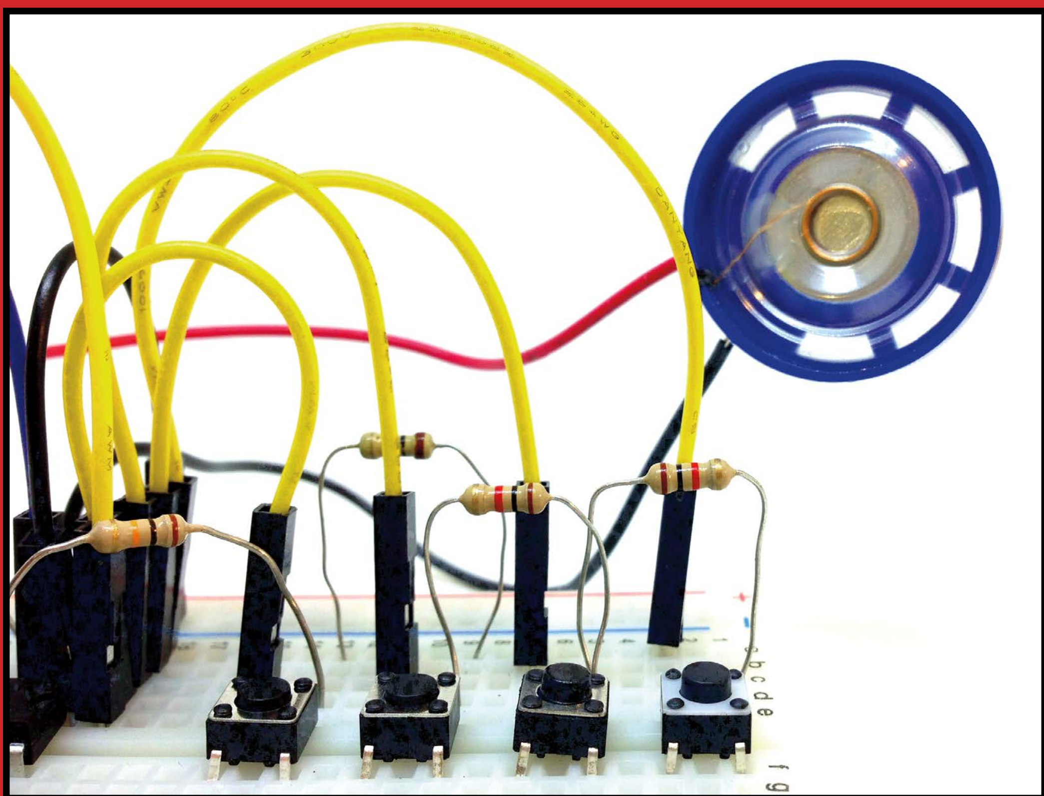
- **Pin 1 Ground** This pin is connected to the negative side of the battery.
- **Pin 2 Trigger** When this pin goes low (less than one-third of V_{CC}), the output goes high.
- **Pin 3 Output** The output voltage from the chip is around 1.5 V lower than V_{CC} when high and around 0 V when low.
- **Pin 4 Reset** This pin resets the whole circuit. It's an "inverted" pin, which means it resets when the pin goes low. This means the pin must be high normally so that the chip isn't in a "reset" state.

- **Pin 5 Control Voltage** This pin is used to control the threshold voltage of the Threshold pin. This can be useful when you want to adjust the frequency of the circuit without changing the values of R1, R2, and C1. For this circuit, you can leave it unconnected. Sometimes you'll see this pin connected with a capacitor to ground; this is a way to keep any noise on it from influencing the frequency.
- **Pin 6 Threshold** This pin sets the output back to low when the voltage goes high (above two-thirds of V_{CC}).
- **Pin 7 Discharge** This pin is unconnected when output is high, and it's connected to ground when output is low.
- **Pin 8 V_{CC} Supply** This is the positive power supply pin and can take a voltage between 5 and 15 V.

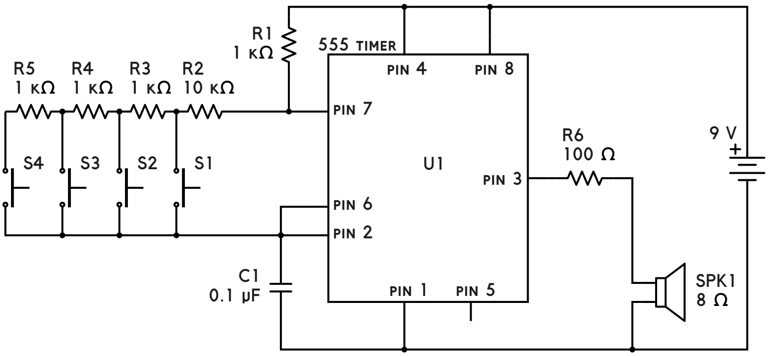
8

THE DIGITAL PIANO

THIS PROJECT'S FOUR BUTTONS PLAY FOUR UNIQUE TONES.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1	1 kΩ	Standard resistor
R2	10 kΩ	Standard resistor
R3–5	1 kΩ	Three standard resistors
R6	100 Ω	Standard resistor
C1	0.1 μF	Nonpolarized capacitor
U1	NE555	555 timer IC
S1–S4	Momentary ON	Four tactile mini-pushbuttons
SPK1	8 Ω	Mini-speaker

ABOUT THE CIRCUIT

In this circuit, you'll build a musical instrument with four buttons that play four different tones.

To create sound, you need to send an oscillating voltage to the speaker. So, you'll use a 555 timer to create a voltage that goes on and off rapidly—meaning a few hundred times per second!

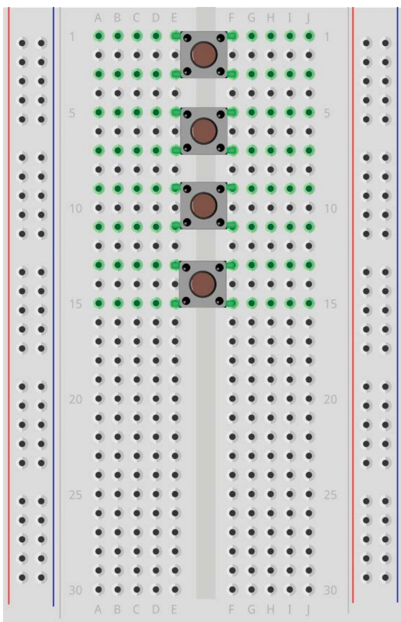
The value of capacitor C1, the value of resistor R5, and the resistance between pins 6 and 7 will set the tone of the sound. You'll place resistors between each pushbutton, so pressing a button affects the circuit's resistance. That means the resistance between pins 6 and 7 will differ depending on which button you push, resulting in a different tone for each.

A pushbutton has four pins. When you look at it from the point of view shown in Figure 8-1, the two pins in front are always connected to each other. The same is true for the two pins in the back. When you push the button, the front pair gets connected to the back pair.

FIGURE 8-1
A pushbutton has four pins.

My preferred way to connect the pushbuttons for this project is across the gap in the middle of the board, as shown in Figure 8-2. This gives you plenty of room to connect the resistors and necessary wires. Don't worry about the rotation, as the pushbuttons will only fit one way.

FIGURE 8-2
Connect the pushbuttons so they span the gap.



It's a good idea to build the circuit with just one button first. Start by connecting button S1. Then add the three other buttons once you've gotten the first one working.

COMMON MISTAKES

If you're having trouble getting the circuit to work correctly, check that you haven't made one of these common mistakes:

- Connecting the 555 timer the wrong way
- Mixing up the pin numbers of the IC and connecting components to the wrong pin
- Forgetting to connect a wire (With so many connections, it's easy to lose track!)

If you want more than four buttons on your keyboard, you can add more pushbuttons and resistors.

If you're struggling with this circuit, you can ask questions and make comments through the book's website at *https://nostarch.com/circuits/*.

WARNING

Make sure the resistor R6 is in series with the speaker for two reasons: (1) to limit the current to the speaker so that even very small speakers don't break and (2) to make sure you don't destroy the IC by squeezing out more current than it can handle.

HOW THE CIRCUIT WORKS

In the previous chapter, you learned how the 555 timer works. This circuit works in the same way, except that in Project 7 the output turned on and off slowly, maybe one time per second. In this circuit, the output switches on and off several hundred times per second!

The capacitor C1 and the resistors R1 to R5 determine how frequently the output (pin 3) switches between a high and a low voltage. To calculate the exact frequency of the sound you hear, you'll use the formula for the switching frequency of a 555 timer:

$$\text{frequency} = \frac{1.44}{((R1 + R_X + R_X) \times C1)}$$

The R_X value is the resistance between pins 6 and 7, so it will depend on which button you push. Let's see what frequency you get when you push S1:

$$R1 = 1\ k\Omega = 1{,}000\ \Omega$$

$$R_X = R2 = 10\ k\Omega = 10{,}000\ \Omega$$

$$C1 = 0.1\ \mu F = 0.0000001\ F$$

$$\text{frequency} = \frac{1.44}{((1{,}000 + 10{,}000 + 10{,}000) \times 0.0000001)}$$

$$\text{frequency} = \frac{1.44}{0.0021} \approx 686$$

If you enter these values into a calculator, you'll get 686. That means the frequency for the first button is 686 Hz.

For the other buttons, here is the value for R_X that you need to enter into the frequency formula:

$$S2: R_X = R2 + R3 = 10\ k\Omega + 1\ k\Omega = 11\ k\Omega$$

$$S3: R_X = R2 + R3 + R4 = 10\ k\Omega + 1\ k\Omega + 1\ k\Omega = 12\ k\Omega$$

$$S4: R_X = R2 + R3 + R4 + R5 = 10\ k\Omega + 1\ k\Omega + 1\ k\Omega + 1\ k\Omega = 13\ k\Omega$$

If you crunch these numbers on a calculator, you should get:

S2: 626 Hz

S3: 576 Hz

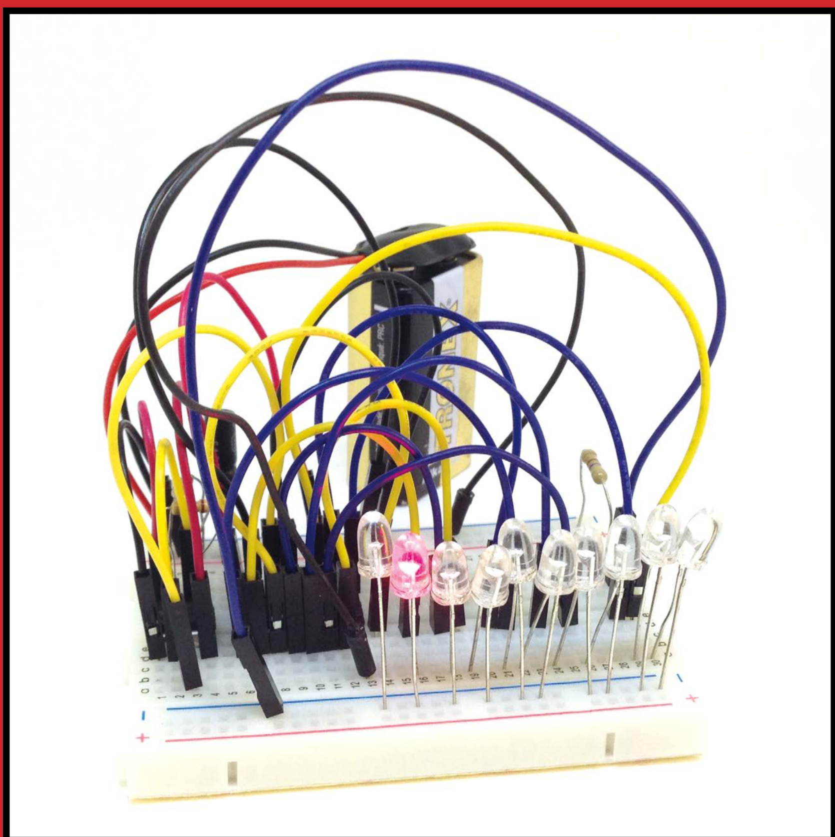
S4: 533 Hz

If you want to change the frequency (or tone) of each button, you need to change the value of resistors R2 to R5. Try changing in increments of 100 Ω first, and then in smaller and smaller increments to fine-tune the tone. Connecting two resistors in series gives you a total resistance equaling their sum.

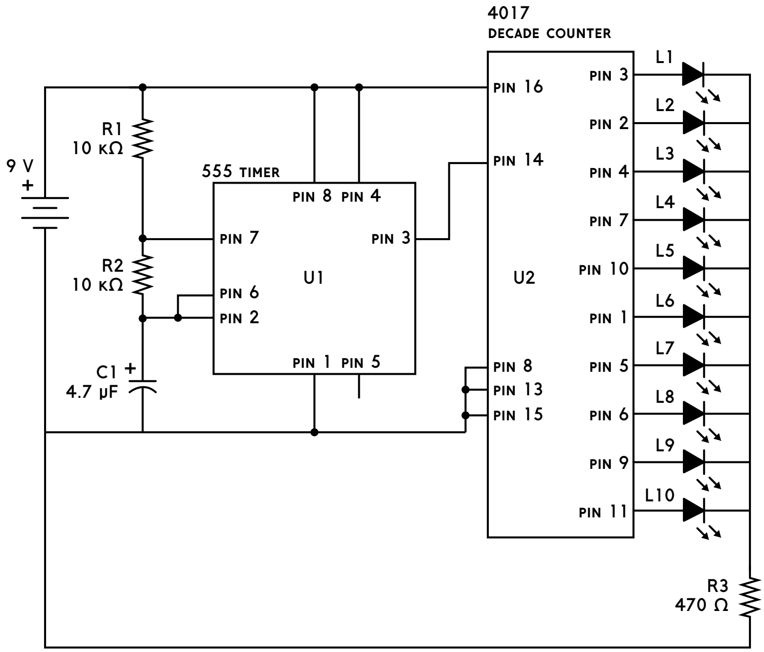
9

THE LED MARQUEE

THIS CIRCUIT CREATES A RUNNING LIGHT, LIKE AN OLD THEATER MARQUEE.



THE CIRCUIT DIAGRAM



THE PARTS LIST

PART	VALUE	DESCRIPTION
R1, R2	10 kΩ	Two standard resistors
R3	470 Ω	Standard resistor
C1	4.7 μF	Polarized capacitor
L1 to L10	LED	Standard light-emitting diodes
U1	NE555	555 timer IC
U2	CD4017B	4017 decade counter IC

ABOUT THE CIRCUIT

This circuit uses a 555 timer and a 4017 decade counter, both integrated circuits. The voltage of the 555 timer's pin 3 switches between high and low repeatedly, as you saw in Project 8. You connect this signal to pin 14 of the 4017 IC, and the 4017 counts the number of times the voltage on pin 14 goes from low to high. The 4017 has 10 outputs—marked Q0 to Q9—that represent this count. For example, after three counts, output Q3 is high, while the others are low. On the 10th count, the counter starts from Q0 again. Figure 9-1 shows the pinout for the 4017 IC.

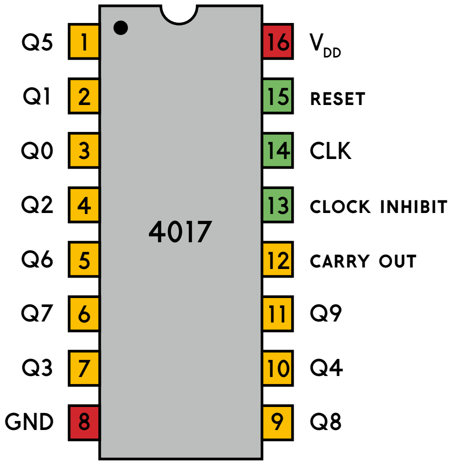


FIGURE 9-1
The pinout for the 4017 IC

The running speed is set by R1, R2, and C1. Change one of the values, and the lights' running speed will change. Larger values slow it down, and smaller values speed it up.

This is a large circuit, so it's pretty easy to connect a wire or a component in the wrong place. I suggest you connect only the 555 timer part first. After that, add a 470 Ω resistor in series with an LED between the 555 output on pin 3 and the negative terminal of the battery. You should see the LED blink really fast. When you do, you can disconnect the LED and resistor and continue connecting the rest of the circuit.

This circuit includes a lot of connections in a small area, so you'll need to be creative with the way you use your space. I recommend you use one of the columns of the left supply area to connect the negative side of the LEDs. This will save you some space.

COMMON MISTAKES

If your circuit isn't working correctly, check that you haven't made any of these common mistakes:

- Connecting one or both of the ICs the wrong way
- Mixing up the pin numbers of the ICs and connecting components to the wrong pin
- Connecting one or more of the LEDs in the wrong way
- Connecting the capacitor the wrong way around
- Connecting a wire or component one row above or below where it should be connected

If you're struggling with this circuit, you can find more resources through the book's website at *https://nostarch.com/circuits/*.

HOW THIS CIRCUIT WORKS

This circuit uses a 555 timer to generate a continuous series of pulses (called *clock pulses*) and a 4017 decade counter to count the number of pulses it receives. LEDs on outputs Q0 to Q9 indicate the count. When the counter reaches 10, it automatically starts from 0 again. This way, it appears as if the LEDs are running from one side to the other, without stopping.

The 4017 IC is easy to use. To get it up and running, just connect the V_{DD} and GND pins to a voltage source. A voltage between 5 V and 15 V will usually work. With the voltage connected, the chip is running and will count any transition from low to high voltage on its CLK (clock) input pin.

Note that each output can provide only about 10 mA of current. If you try to get more current out of each output—for example, by using a smaller resistor value for R3—you risk strange behavior or even chip damage.

The following table provides an overview of each pin's function.

PIN #	NAME	DESCRIPTION
1	Q5	Goes high when the count is 5
2	Q1	Goes high when the count is 1
3	Q0	Goes high when the count is 0
4	Q2	Goes high when the count is 2
5	Q6	Goes high when the count is 6
6	Q7	Goes high when the count is 7
7	Q3	Goes high when the count is 3
8	GND	Ground (0 V) connection
9	Q8	Goes high when the count is 8
10	Q4	Goes high when the count is 4
11	Q9	Goes high when the count is 9
12	Carry Out	High output for counts 0 to 4
13	Clock Inhibit	Counter does not count any clock pulses when this input is high
14	CLK	Input for pulses to be counted
15	Reset	Resets the the count to 0 when high; must be low to count
16	V_{DD}	Positive voltage supply

WHERE TO GO FROM HERE

Congratulations, you've made it all the way to the end!

If you've built all nine circuits, you should have a solid practical foundation for creating great things with electronics. If you're new to electronics, you might not have understood all the details of each circuit in this book, but that's okay. This book was all about building circuits and improving your practical electronics skills.

If you want to understand more about how these circuits work and how you can build your own, check out my book *Electronics for Kids* (No Starch Press, 2016), which will teach you electronics from scratch, even if you're not necessarily a "kid" anymore.

If you want to step up your game and learn to build projects that can do much more advanced things, like use graphical displays, create melodies, and connect to the internet, I recommend exploring a popular device called Arduino (*https://www.arduino.cc/*).

Whether you want to build an automatic cat door for your home or the next must-have gadget for the world, you'll need to develop the skills and knowledge necessary to build those projects. That's why I'm constantly creating new learning material to help people bring their own ideas to life with electronics. To help people from all backgrounds develop these abilities, I've created a learning portal for electronics called Ohmify. It's a place where you can sign up for courses to learn a variety of skills, including:

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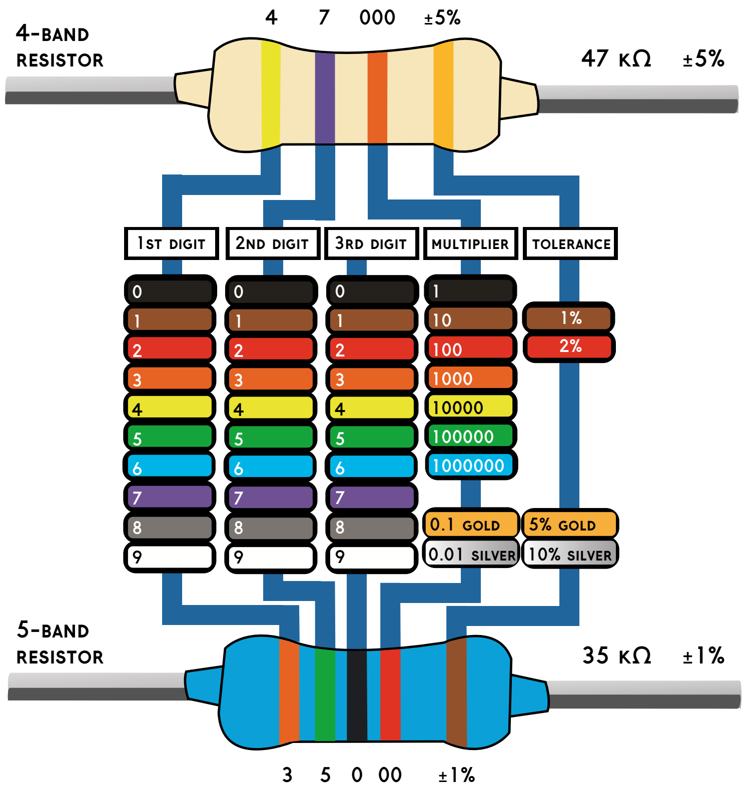

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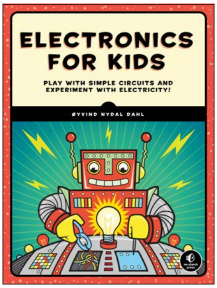

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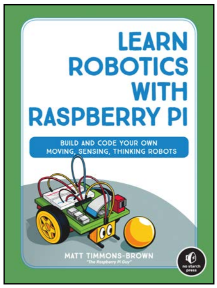

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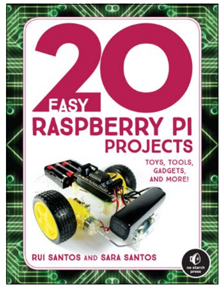

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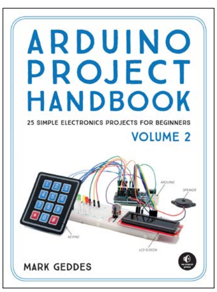

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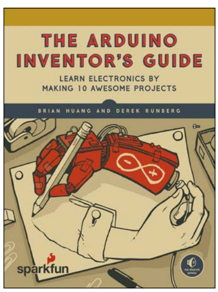

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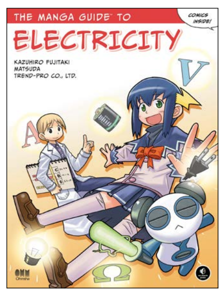

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NO SOLDERING REQUIRED!

A Beginner's Guide to Circuits is the perfect first step for anyone ready to jump into the world of electronics and circuit design.

First, you'll learn to read circuit diagrams and use a breadboard, which allows you to connect electrical components without using a hot soldering iron! Next, you'll build nine simple projects using just a handful of readily available components, like resistors, transistors, capacitors, and other parts. As you build, you'll learn what each component does, how it works, and how to combine components to achieve new and interesting effects.

By the end of the book, you'll be able to build your own electronic creations. With easy-to-follow directions, anyone can become an inventor with the help of *A Beginner's Guide to Circuits*!

BUILD THESE 9 SIMPLE CIRCUITS!

- **Steady-Hand Game:** Test your nerves using a wire and a buzzer to create an Operation-style game!
- **Touch-Enabled Light:** Turn on a light with your finger!
- **Cookie Jar Alarm:** Catch cookie thieves red-handed with this contraption.
- **Night-Light:** Automatically turn on a light when it gets dark.
- **Blinking LED:** This classic circuit blinks an LED.
- **Railroad Crossing Light:** Danger! Don't cross the tracks if this circuit's pair of lights is flashing.
- **Party Lights:** Throw a party with these charming string lights.
- **Digital Piano:** Play a tune with this simple synthesizer and learn how speakers work.
- **LED Marquee:** Put on a light show and impress your friends with this flashy finale.

Øyvind Nydal Dahl built his first circuit at age 14, and has kept building ever since then. Øyvind has a master's degree in Electronics from the University of Oslo, helps companies develop new products, and travels the world while teaching electronics workshops. He is also the author of *Electronics for Kids* (No Starch Press, 2016). Read more about Øyvind at *http://www.build-electronic-circuits.com/*.

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