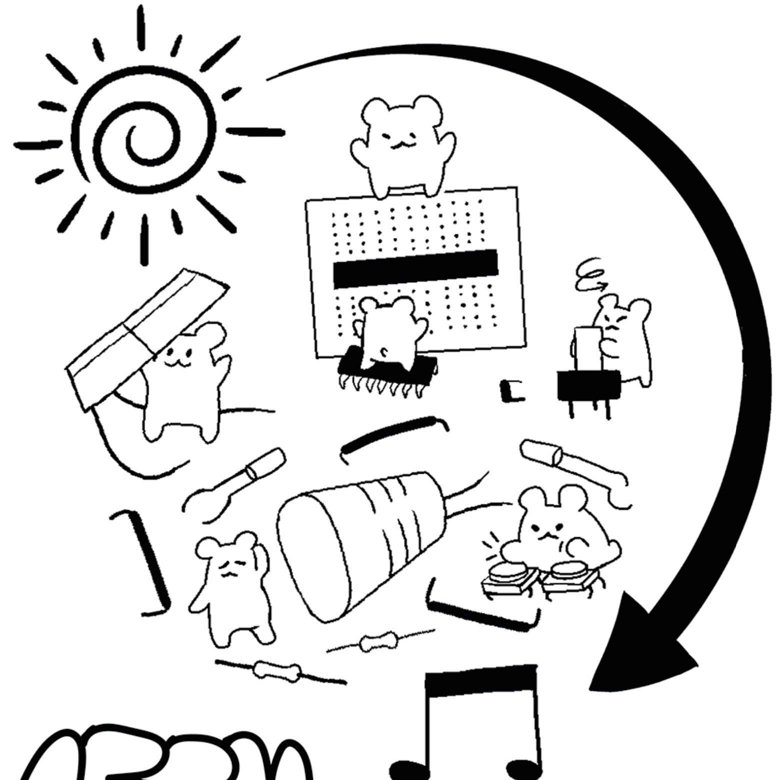
IFFY BOOKS

Build a Solar-Powered Music Synth



IFFY BOOKS

319 N. 11th St. #3E
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Questionnaire

It would be super helpful if you'd complete the survey below at the end of today's workshop. Thank you!

Submit a photo of the page via text message (**215-395-3956**) or email (**iffybooks@iffybooks.net**).

Or go to https://iffybooks.net/solar-survey and complete the survey online. You can also use it to provide more extensive feedback with the option for **anonymity.**

Did you finish building a working circuit with an on/off switch?
❏ **yes** ❏ **no**

Did you finish adding an additional capacitor to your circuit?
❏ **yes** ❏ **no**

Did you finish adding a potentiometer to your circuit?
❏ **yes** ❏ **no**

How fun was this workshop?
❏ **1** (not fun) ❏ **2** ❏ **3** ❏ **4** ❏ **5** (super fun)

How much did you learn?
❏ **1** (nothing) ❏ **2** ❏ **3** ❏ **4** ❏ **5** (a lot)

This survey continues online at the following URL. Thanks for your feedback!

https://iffybooks.net/solar-survey

To Catch the Sun by Joshua Pearce and Lonny Grafman (2021)

DIY Solar Power: How to Power Everything from the Sun By Micah Toll (2017)

Make: Analog Synthesizers: A modern approach to old school sound synthesis by Ray Wilson (2013)

A Beginner's Guide to Circuits: Nine simple projects, with lights, sounds, and more! by Øyvind Nydal Dahl (2018)

The Crafty Kids Guide to DIY Electronics: 20 Fun Projects for Makers, Crafters, and Everyone in Between by Helen Leigh (2018)

Community Organizations and Programs

Philly Component Library (Thanks to a workshop participant for sharing this!)
https://www.soundmuseumcollective.org/resources

Playbrary
https://www.play-brary.org

West Philly Tool Library
https://westphillytools.org

The Resource Exchange: Philadelphia's Creative Reuse Center
https://theresourceexchange.org

Solarize Philly
https://solarizephilly.org

Updated 16 November 2022

Table of Contents

Acknowledgments

The development of this kit and its companion zine was made possible with the funds from the Swarthmore College Lang Center for Civic and Social Responsibility's Engaged Humanities Studio Fellowship Grant awarded to Chris and Iffy Books for the "Iffy Solar" project.

Inspiration for this kit was derived from Ralf Schreiber's Solar Sound Module Project (http://www.ralfschreiber.com/solarsound.html).

Thank you to Steve, Chris, and Matty for your contributions.

Additional Resources

Previous Work

Guide from a Solar Sound Module Workshop held by Shannon McMullen and Fabian Winkler from the Electronic and Time-Based Art program:
https://cla.purdue.edu/academic/rueffschool/ad/etb/resources/solar_sound_module.pdf

Schedule, description, and video of previous solar workshops by Ralf Schreiber at the SolarKrA festival featuring the Solar Sound Module:

1 https://web.archive.org/web/20190302071610/http://yo-yo-yo.org/en/harmonogram-solarni-dilny/
2 https://vimeo.com/81919040

Description and photo records from a Solar Sound Bot Workshop held by J Milo Taylor:
http://netzzz.net/solar-sound-bots

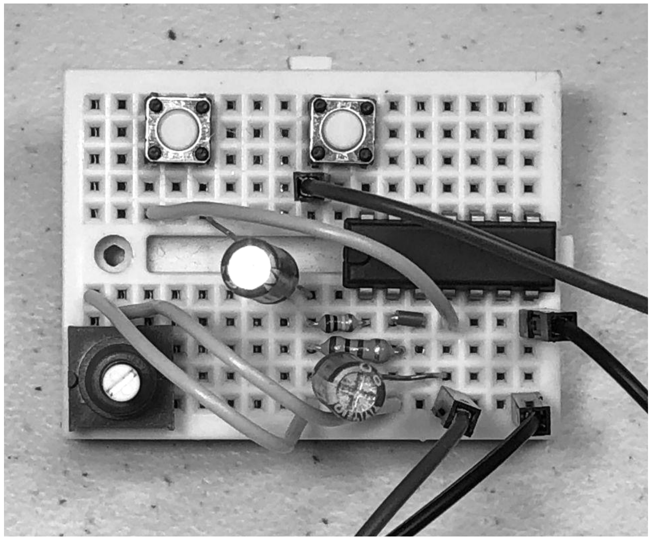
Browsing Material

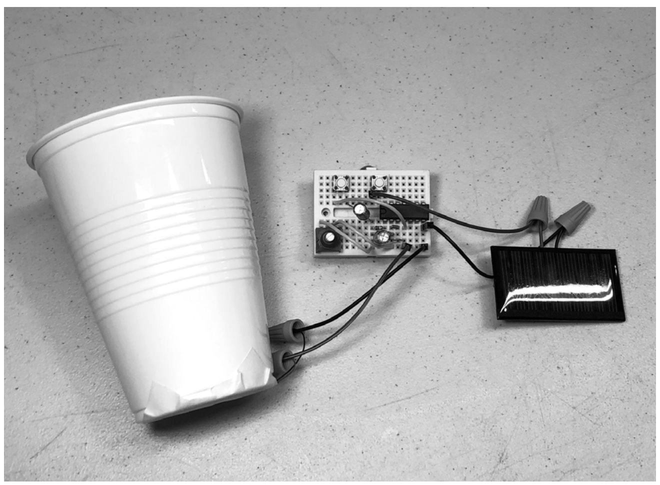
An Introduction to Sound by Bartosz Ciechanowski
https://ciechanow.ski/sound

The Creative Solar Power Archive
https://www.solarpowerforartists.com/archive

Solarsonics: Sound Driven Sound and Music Collection
https://solarsonics.ca

Here's the finished circuit!





Introduction

What You'll Be Building Today

In this workshop you'll build a circuit that turns solar energy into electronic music — a.k.a. our Solar-Powered Synth. Here's an overview of what you'll do:

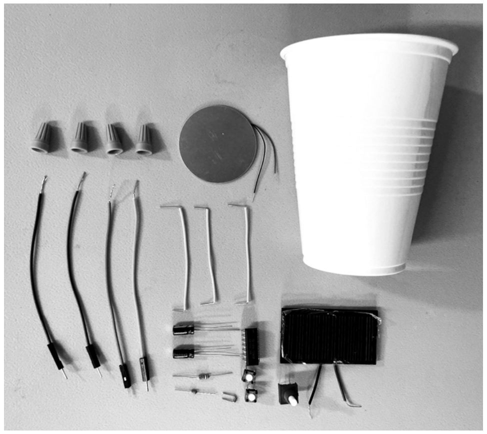
1. Build an oscillator circuit that generates a square wave, with a push button switch to turn it on and off.
2. Modify your circuit by adding a capacitor, letting you push a button to lower the frequency by an octave.
3. Add a potentiometer to your circuit, letting you change the frequency by turning a knob.
4. Play music in the sunshine!

If you **don't have any experience with electronics**, you're in the right place! We've provided step-by-step instructions with pictures, aimed toward beginners. Follow along with the check boxes to keep track.

If you have **lots of electronics experience**, you're also in the right place! You can skip ahead if you want, make further modifications, and/or help other people at your table.

Materials

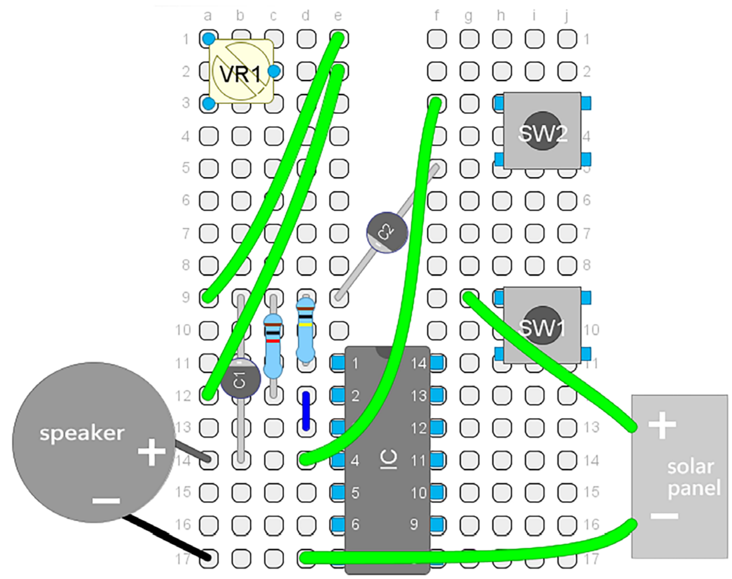
What You'll Find in Your Kit



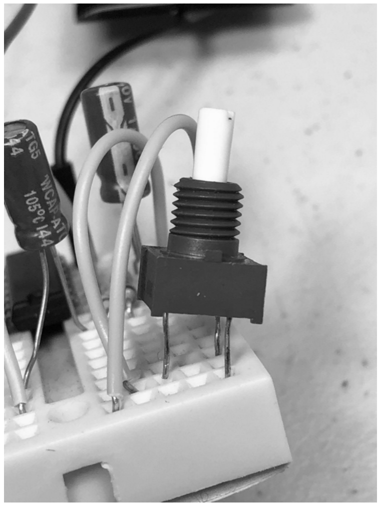
- 1 breadboard (170 tie points or larger)
- 1 solar panel (5 V, 30 mA or similar)
- 1 passive piezo speaker (41 mm or similar)
- 1 SN74HC14 integrated circuit (IC)
    - This type of IC is called a hex inverter, because it has six logical NOT gates (a.k.a. inverters).
    - Data sheet: https://www.ti.com/product/SN74HC14
- 2 resistors (1 kΩ and 100 kΩ)
- 2 electrolytic capacitors (1 uF, max 50 V)
- 1 potentiometer (100 kΩ)
- 2 momentary push button switches
- 3 22-gauge single-strand jump wires (~5 cm, plus 1 cm stripped on each end)
- 1 short single-strand jump wire (~2 mm, plus 1 cm stripped on each end)

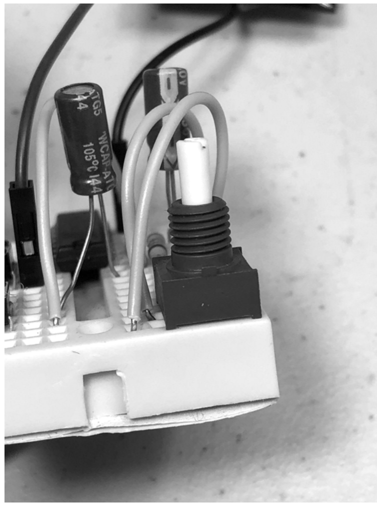
> ***Note:*** *Twisting the knob all the way counterclockwise may cut off the sound. Twist it back a bit the other way to hear it again.*

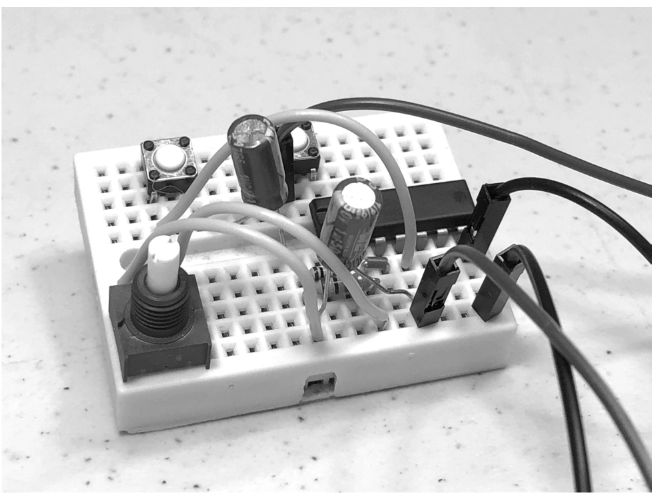
Here's a rendering of the finished modification:



Insert the potentiometer into your board. The center pin (wiper) and one of the terminals should connect to the jump wires from the previous step.







Press **SW1** and **SW2** and turn the knob on **VR1**. You should be able to adjust the frequency!

- 4 one-sided DuPont jump wires (plug-ends) with the wire side stripped to 1 cm
- 4 22-gauge wire nuts
- 1 lightweight plastic cup (optional; we had them lying around)
- ~15 cm masking tape (optional)

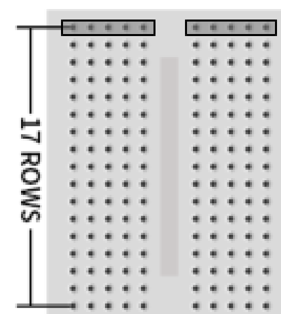
You'll learn more about these items in the Build Layout section.

Note: The wires in your kit are pre-stripped. If any wires in your kit have loose pieces of insulation on the end, you can remove and discard them now.

If the end of a wire breaks off, ask for help. Or carefully re-strip it using wire strippers, wire cutters, or a pair of scissors.

Build Layout

Breadboard

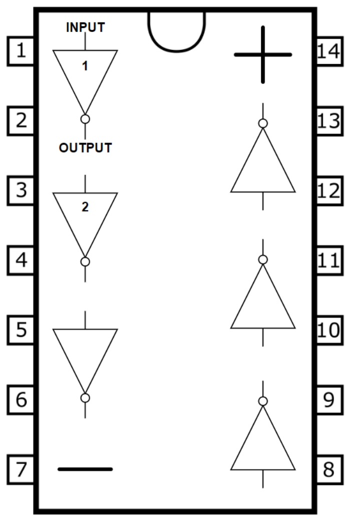


You'll build your circuit on a breadboard, letting you connect wires and components without soldering. The breadboard in your kit has **17 rows**, with two **terminal strips** in each row. Each terminal strip has **5 tie points**, which are connected by a metal clip.

The empty space running through the center of your breadboard is called the centerline. Its width is designed to match **Dual**

In-line Package (**DIP**) ICs, letting them straddle the gap and connect to terminal strips on both sides of the breadboard.

Integrated Circuit

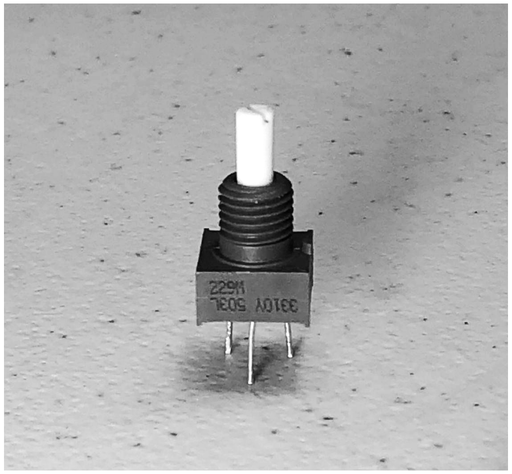


The **integrated circuit** (**IC**) we're using has 14 pins with six 2 V-to-6 V **NOT gates** (a.k.a. **inverters**). A semicircle notch on one side indicates the orientation of the IC.

You'll use two NOT gates to create your circuit, so you'll primarily focus on pins 1–4. Pins 1 and 2 are the input and output of the first NOT gate, as shown in the image above. Pins 3 and 4 are the input and output of the second NOT gate.

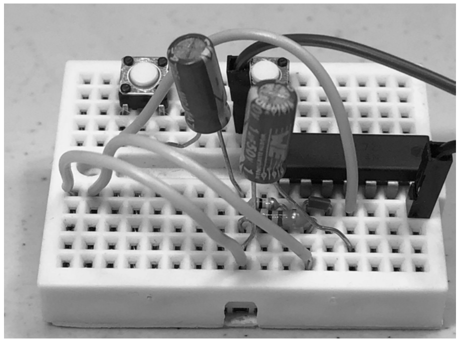
Pins 7 and 14 are the IC's negative and positive terminals, where you'll connect your solar panel.

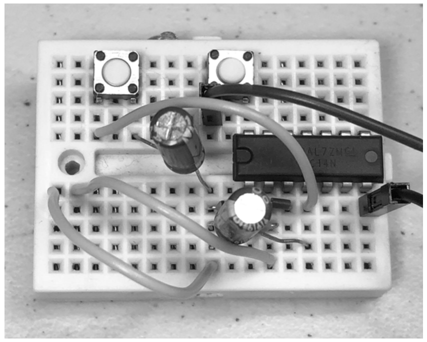
Your potentiometer has three legs. The center leg connects to the potentiometer's **wiper**. Turning the knob varies the resistance between the **wiper** and **the two other terminals**.



> ***Note:*** *You may want to disconnect the piezo speaker to make room for this step, as we did in the photos below.*

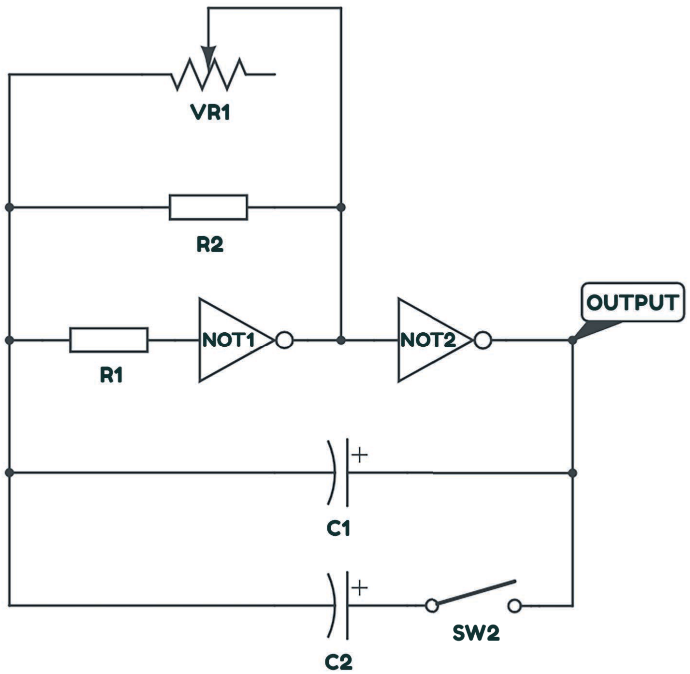
Connect **two single-strand jump wires** to the ends of **R2**, then connect the other ends to **two empty terminal strips** on the left side of the board. (Depending on the size of your potentiometer, you may need to leave an extra row between these two wires.)





Modification 2

Let's add a potentiometer in parallel with R2 to adjust the frequency.



❏ In this step you'll connect a **100 kΩ potentiometer in parallel with R2**, which will let you adjust the frequency. We'll call the potentiometer **VR1**, because we're using it as a variable resistor.

What is a NOT gate?

A **NOT gate**, or **inverter**, is an example of a **logic gate**. Logic gates are the building blocks of computers: They execute logical operations using binary 1s and 0s (high voltages and low voltages, respectively).

Here's a table that describes the behavior of a NOT gate:

NOT gate truth table	
Input	**Output**
1 (high voltage)	0 (low voltage)
0 (low voltage)	1 (high voltage)

If you think of **0** as **false** and **1** as **true**, the truth table above is the same as the **NOT** operation in formal logic.

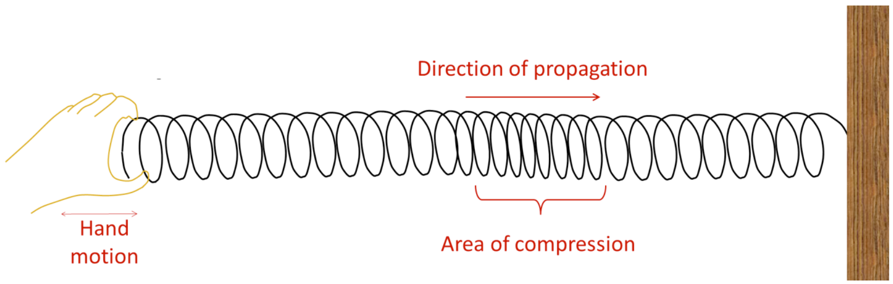
Each NOT gate on your IC has a Schmitt trigger, which sets threshold values for **low** and **high** voltages. These threshold values vary depending on the voltage of the IC's power source. The ICs we're using are designed to operate over a wide range of voltages, from 2 V to 6 V.

What is a wave?

Sound moves through space as a series of oscillations in air pressure, with regions of high pressure alternating with regions of low pressure.

Humans can hear sound waves from around 20 Hz (20 complete oscillations per second) to 20,000 Hz.

The air behaves a bit like a Slinky stretched across a table. If you wiggle one end in the direction the Slinky is stretched, you'll send a compression wave to the other end of the table. After a few seconds, the Slinky returns to its original position.



CC-BY Steven Earle: opentextbc.ca/geology/chapter/9-1-understanding-earth-through-seismology

We use the term **sound pressure level** (**SPL**) to describe the air pressure at a given point in time. To send sound through a wire, we can translate between oscillations in SPL and oscillations in **voltage.**

A **microphone** takes oscillations in SPL and produces oscillations in voltage, which can then be amplified and/or recorded. A **speaker** does the opposite, turning oscillations in voltage into oscillations in SPL.

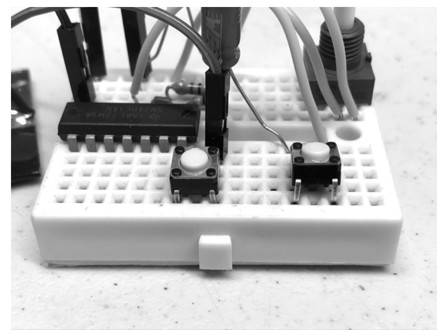
An **audio synthesizer** is a circuit that generates oscillations in voltage in the human hearing range (20 Hz–20k Hz). When you connect a synthesizer to a speaker, you get sound!

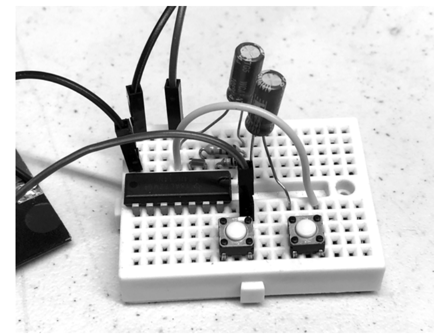
What is a square wave?

The circuit you'll build in this workshop will make two NOT gates oscillate rapidly between **high** and **low** voltage levels, creating a

Now you'll add a **switch** (**SW2**) connecting the positive side of C2 and the single-strand jump wire two rows over.

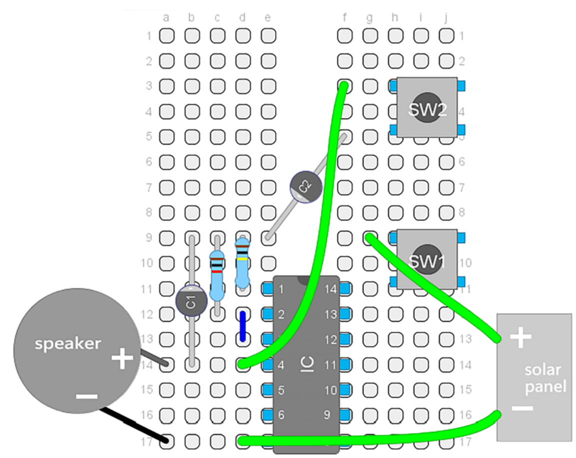
Line up the switch to match the photo on the left, then push it in.



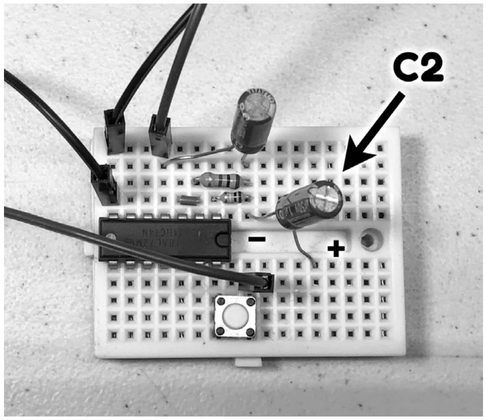


Press **SW1** and you should hear a tone. Press **SW2** while SW1 is pressed down, and the tone's frequency should drop by an octave.

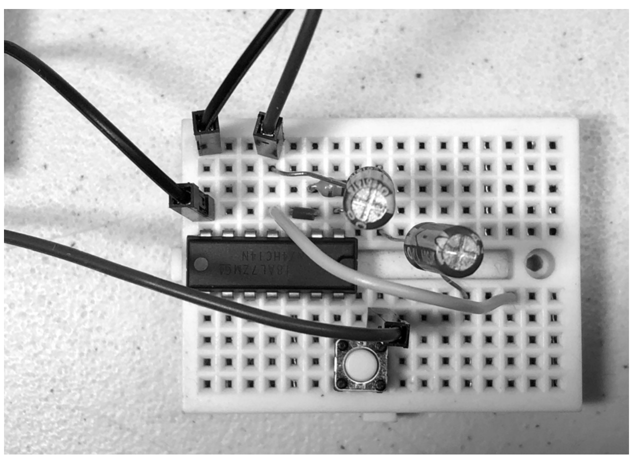
Here's a rendering of the circuit at this point:



Connect the **negative (short)** side of the capacitor to **the same row where C1, R1, and R2 connect.** Then connect the **positive (long) side** to an **empty row** across the centerline.

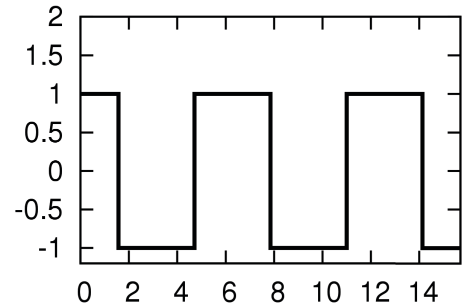


Connect one end of a **single-strand jump wire** to the **same row as the positive side of C1.** Connect the other side **two rows over from the positive side of C2.**



square wave. You may recognize the sound of a square wave from electronic music and old video games.

Here's an illustration of a square wave, with time on the x-axis and voltage/SPL on the y-axis:

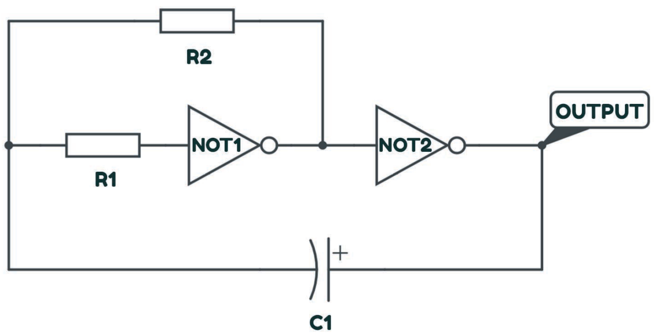


In the image above (which is somewhat idealized), the voltage level flips back and forth between high and low values, which a speaker can turn into oscillations in SPL. A 500 Hz square wave has 500 complete oscillations per second.

A square wave generator like this one can also be used as a digital clock, helping keep time like a metronome in an electronic device.

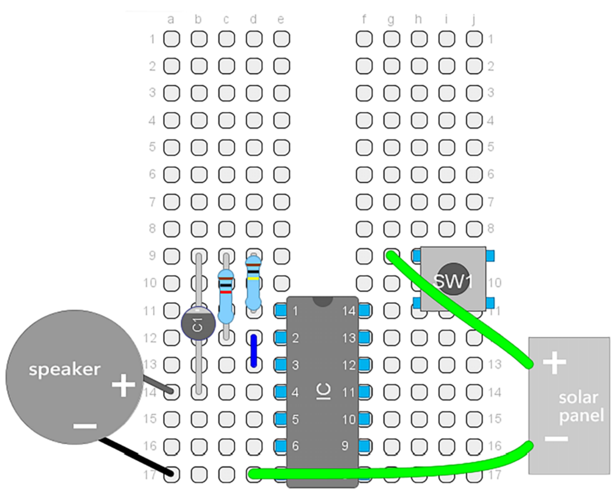
Build Instructions

Steps for the basic circuit



Note: The diagram above is slightly simplified, omitting the power source. That's because the two NOT gates are being powered by the IC.

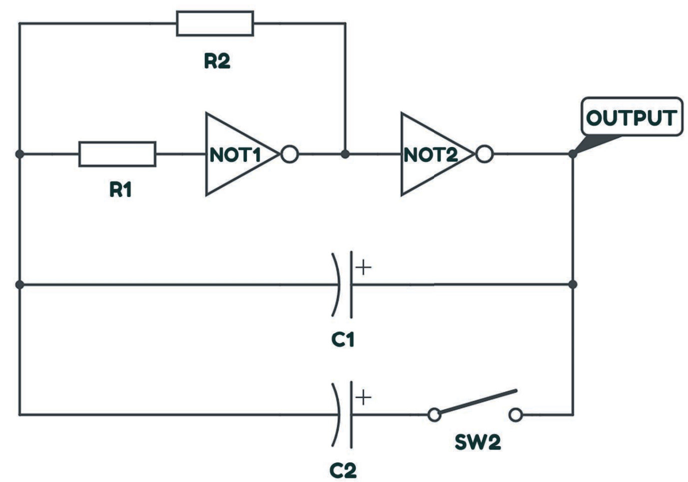
Here's a rendering of the finished circuit, which you can refer back to as needed:



Build Upgrades

Modification 1

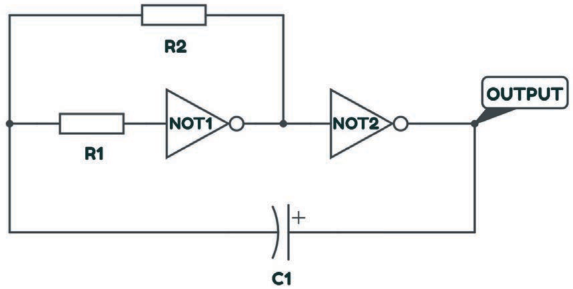
Let's add a capacitor in parallel with C1 to increase capacitance and lower the frequency.



❏ In this step you'll add a **switch** (**SW2**) that connect an additional **1 uF capacitor** (**C2**) in parallel with **C1.** When you push the button on **SW2** you'll connect the **positive side of C1 to the positive side of C2**, and the **negative side of C2 to the negative side of C1.**

Find the other **1uF capacitor** in your kit, and remove the tape and cardboard. This will be **C2.**

How Does It Work?



At the output of each NOT gate, the voltage is always either high or low. When the voltage level at the input of a NOT gate is low, the output side flips to high, and vice-versa.

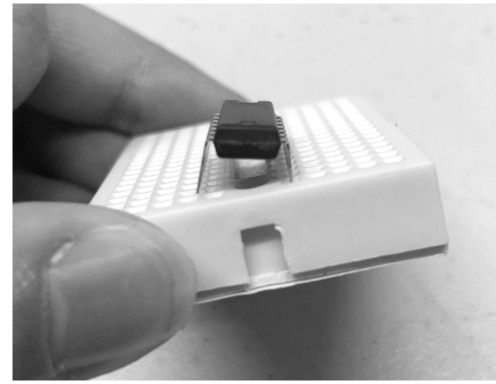
To understand why this circuit oscillates, let's focus on the output side of **NOT1**, which connects to **R2** and the input to **NOT2**.

When the voltage at this point is **high**, current flows through **R2** and gradually charges **C1**. As **C1** charges, the voltage at its negative terminal goes up. When the voltage at the **input of NOT1** passes the upper voltage threshold and becomes **high**, the gate's **output** flips to **low.**

Because the **output of NOT1** in the circuit has a low voltage, **C1** will discharge its stored energy through **R2**, gradually lowering the voltage at the input to **NOT1.** Once the voltage falls below the lower threshold, the input to **NOT1** will switch to **low** and the output will switch to **high.**

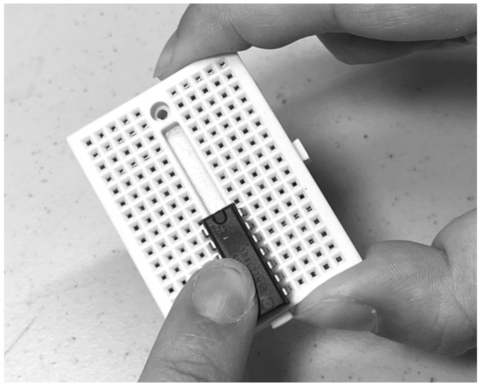
At this point we've completed a single oscillation, and the process repeats.

❏ The first step is to attach the IC to the breadboard. Start by positioning the IC over the centerline and check whether the pins line up with the holes on either side.

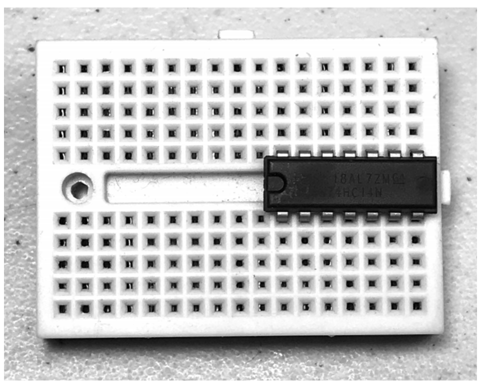


If the pins are too wide to fit, you can use something flat (like the edge of a pencil) to carefully squeeze them inward. It may take a few tries to get the correct width.

With your breadboard oriented vertically, you'll attach the IC at the far bottom of the board. Line up the IC over the centerline, with the notch on the IC pointing toward the top of the board. Now gently press the IC's pins into the breadboard.

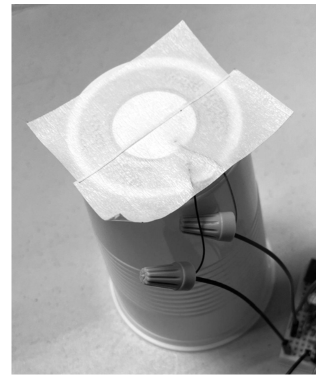
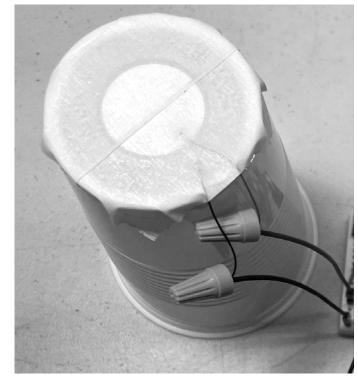


Rotate your breadboard counterclockwise, so it looks like this:



❏ (Optional) To make your piezo speaker easier to hear, you can use a lightweight cup to make an improvised horn loudspeaker. We're using plastic cups because we had them lying around.

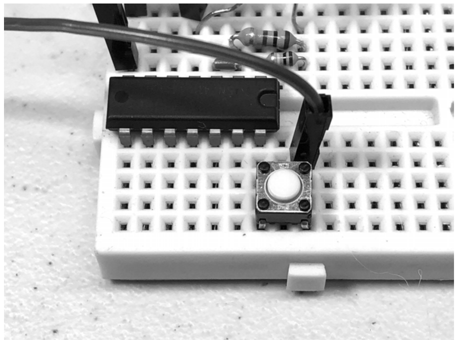
Align the flat side of the piezo in the center of the bottom of the cup, then tape it down with masking tape. Make sure the wires are taped down securely to avoid strain on the solder joints.

Flip the cup right-side-up (piezo speaker on the bottom) and press SW1. Do you hear a difference?

Congratulations! You've made a solar-powered synth!

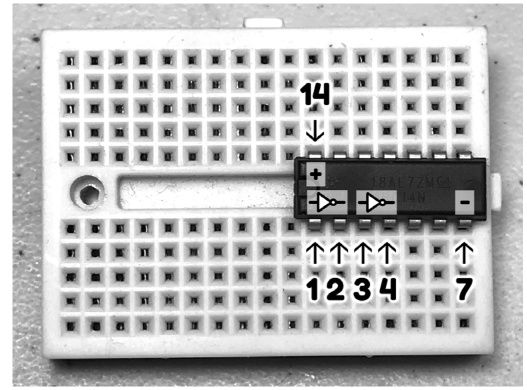
Plug the **red wire from your solar panel** into the same row as the right side of the switch.



Push the button on **SW1** and check whether you hear a sound. If you don't hear anything, try removing the switch and rotating it 90°.

Use your push button switch to make a little beat!

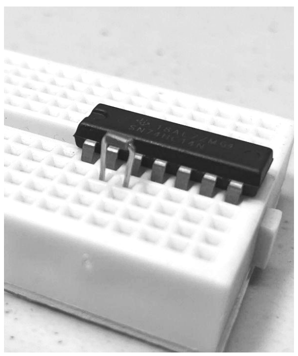
For this project you'll only need to use six of the IC's pins, which are labeled below.

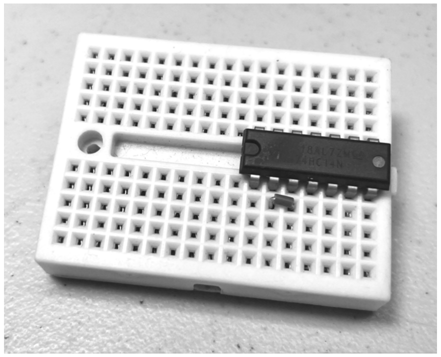


Pins **1** and **2** are the input and output of a NOT gate, which we'll call **NOT1.** Pins 3 and 4 are the input and output for another NOT gate, **NOT2.**

Pins **7** and **14** are used to power the board. You'll attach your solar panel's **ground wire (–) to pin 7**, and its **positive wire (+) to pin 14.**

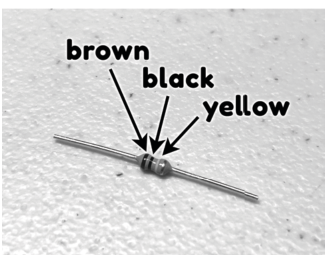
❏ Find your **2 mm single-strand jump wire**, the smallest part in your kit. Use the wire to **connect pin 2 and pin 3** on the IC. You've just connected the output of NOT1 to the input of NOT2.

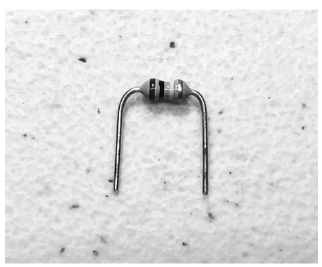




❏ Find the **100 kΩ resistor** in your kit, which has color bands in the following order: **brown, black, yellow, gold**. We'll call this resistor **R1**.

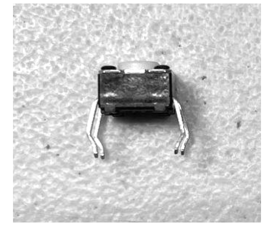
Gently bend the resistor's leads to make a staple shape.

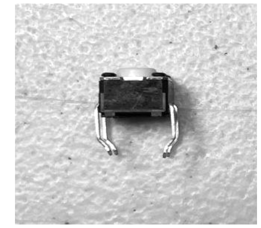




brown means "1", black means "0", yellow means "times 10 kΩ"
10 x 10 kΩ = **100 kΩ**

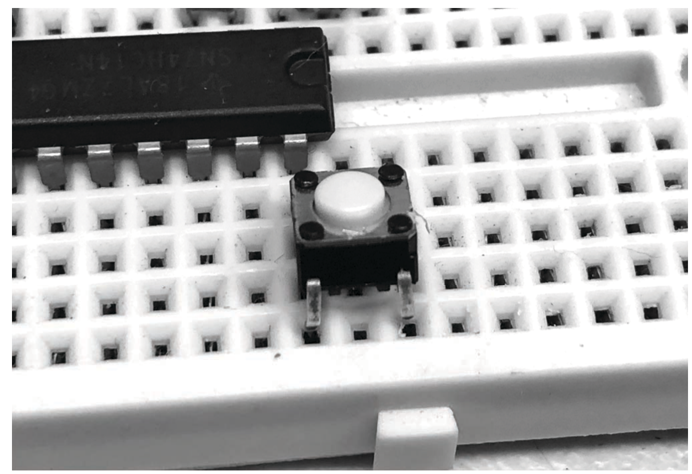
Check whether the legs of the switch line up with the holes on the breadboard. You'll most likely need to squeeze the switch's legs together to make it fit.





Turn your breadboard 180°, so pins 8–14 on the IC are facing you.

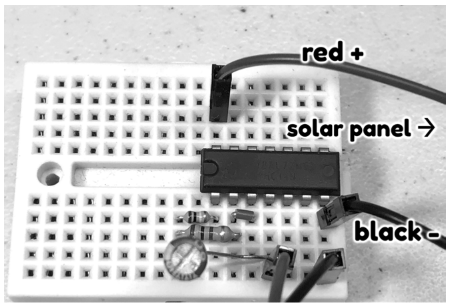
Line up your switch on the breadboard, like in the photo below. One side will be connected to **pin 14** on the IC and one side will be on an empty row to the right of the IC.



❏ Now you'll hook up the solar panel and make some sound!

Connect the **black wire** from the solar panel to **pin 7** (ground) on the IC.

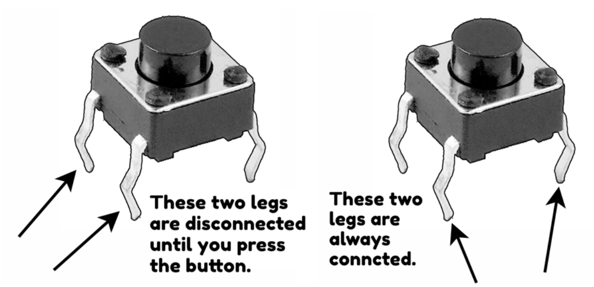
Connect the **red wire** from the solar panel to **pin 14** (positive) on the IC. If you're in a well-lit place, the piezo should start making noise as soon as you connect the power.



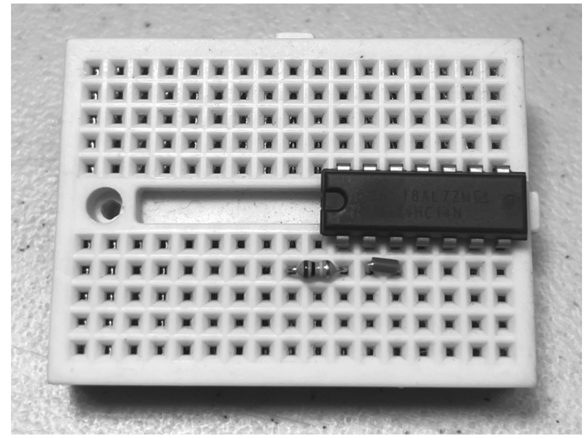
Unplug the solar panel from **pin 14** and the sound will stop.

❏ Next you'll add an on/off switch to your circuit, which we'll call **SW1**.

Find a push button switch in your kit and look closely at the legs. The switch's four legs are made of two metal strips that resemble staples. Pushing the button makes a connection between the two strips.

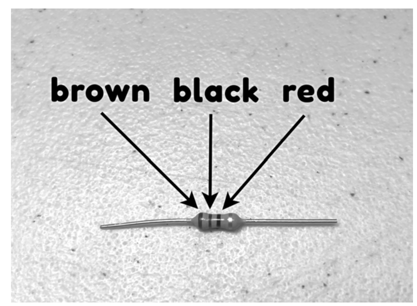


❏ Connect one side of R1 to the input of NOT1 (pin 1 on the IC) and the other side to an empty terminal strip to the left of the IC. The resistor's orientation doesn't matter.



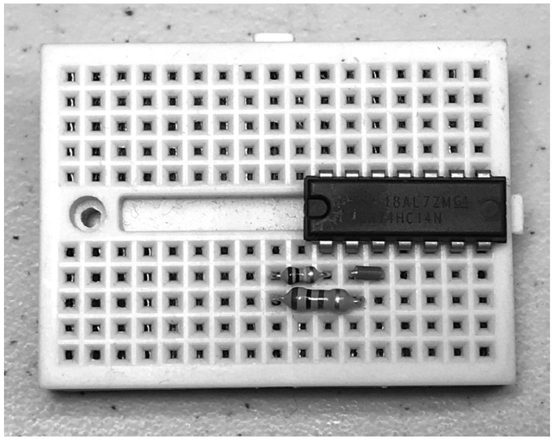
❏ Find the **1 kΩ resistor** in your kit, which has color bands in the following order: **brown**, **black**, **red**, **gold**.

Gently bend the resistor's leads to make a staple shape.

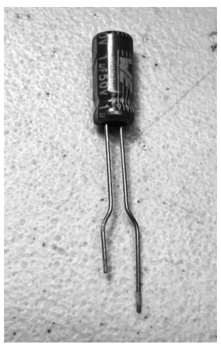


brown means "1", black means "0", yellow means "times 100 Ω"
10 x 100 Ω = 1000 Ω = **1 kΩ**

❏ Connect one side of **R2** to the **output of NOT1 (pin 2)**. Connect the other side to the terminal strip to the left of the IC that you used in the previous step.

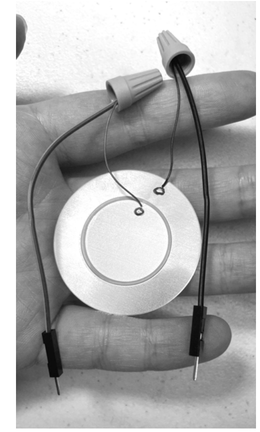


❏ Find a **1 uF capacitor** in your kit, which we'll call **C1**.



The capacitors we're using are **polarized**, which means they need to be oriented in a specific direction. The long lead is the positive (+) side, and the short lead is negative (–). Many polarized capacitors also have a white stripe running along the negative side.

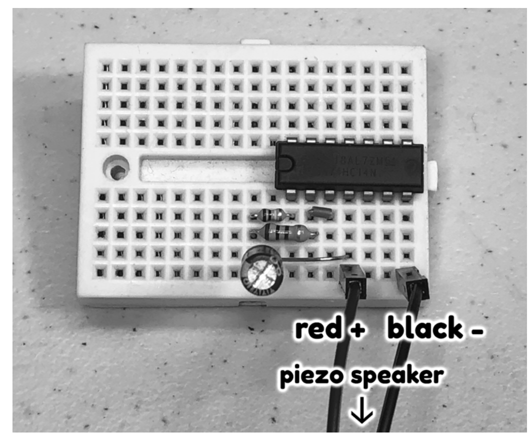
Push the wires into the wire nut and gently twist the wire nut clockwise. Then repeat the process for the piezo's other wire.



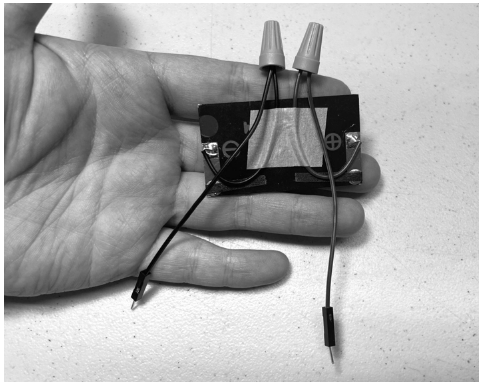
❏ Next you'll connect your piezo speaker to the IC. Look at your piezo and note that it has one red wire and one black wire soldered onto the back.

Take the DuPont wire that connects to the **red wire** on your piezo (the positive side) and connect it to **pin 4** on the IC. This pin is the output of **NOT2**, and it's where the audio signal will come from.

Take the DuPont wire that connects to the **black wire** on your piezo (ground) and connect it to **pin 7** on the IC (also ground).

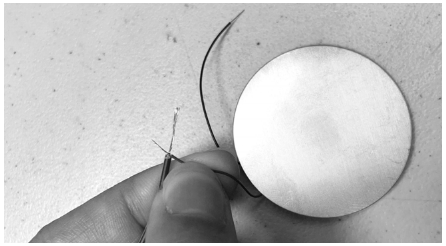


Repeat the process for the other wire on your solar panel.

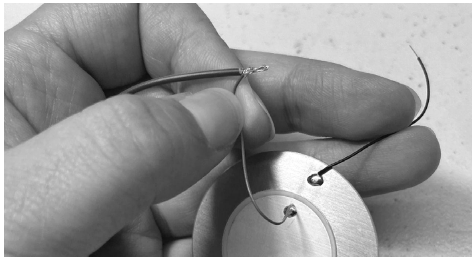


❏ Now you'll connect DuPont wires to the piezo speaker.

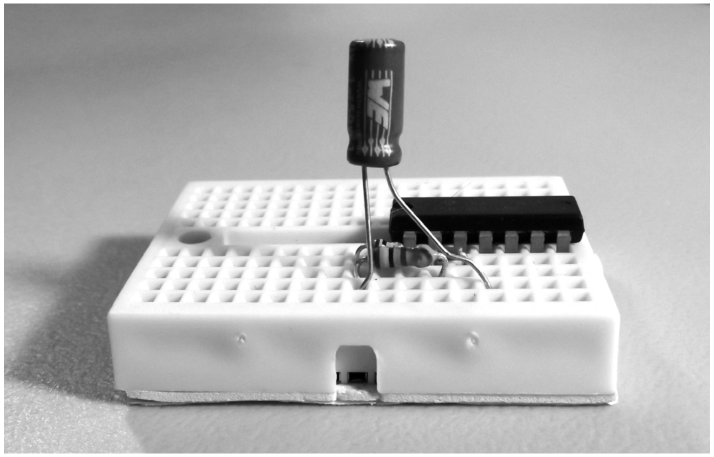
Cross the stripped end of a DuPont wire with the end of a wire on your piezo speaker.



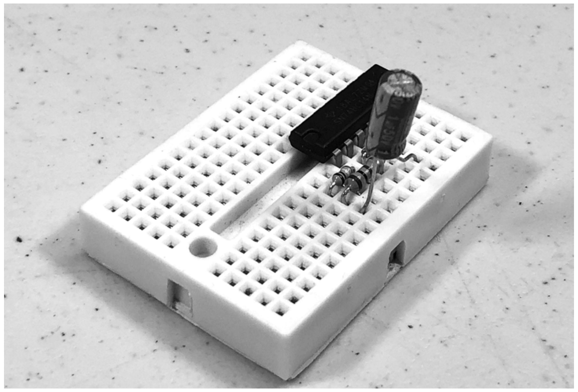
Gently twist the wires together. They should hold together on their own when you're done.



Connect the capacitor’s **positive (long) lead to pin 4** on the IC. Then connect the negative lead to the same row where R1 and R2 are connected.



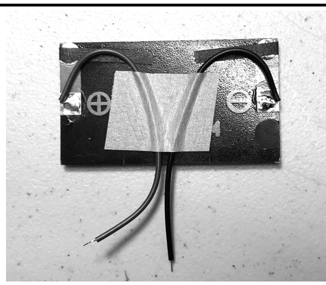
Here's an alternate angle, showing the white stripe on the negative (–) side:

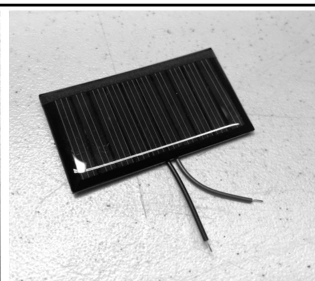


❏ Next you'll connect DuPont jump wires to the wires on your solar panel. These are the wires with a rectangular plastic end that holds a metal pin. This step is needed because the wires on your solar panel are too small to plug directly into your breadboard.

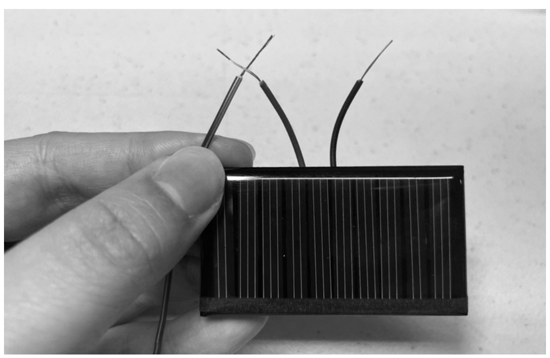
Find your solar panel and two DuPont wires. If your solar panel is covered in a sheet of plastic, you can remove it now.

> **Note:** For this workshop we've taped down the wires on each solar panel to avoid putting stress on the solder joints.

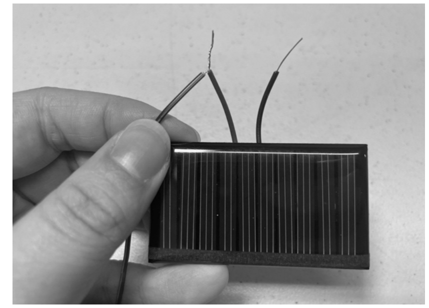




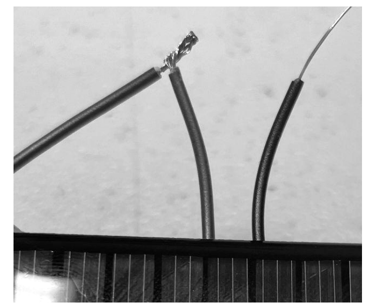
Cross the stripped end of a DuPont wire with the end of a wire on your solar panel.



Gently twist the stripped ends together. They should hold together on their own when you're done.



Fold the stripped wires in half and squeeze them together. This will help them fit all the way into the wire nut.



Insert the wires into a wire nut. Gently twist the wire nut clockwise until the connection feels snug.